PB81-118895

The Cost of Alternative Flue Gas Desulfurization (FGD) Sludge Disposal Regulations

SCS Engineers
Long Beach, CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Nov 80

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-80-178

2.

3. RECIPIENT'S ACCESSION NO.
PB81 118895

4. TITLE AND SUBTITLE
The Cost of Alternative Flue Gas Desulfurization (FGD)
Sludge Disposal Regulations

5. REPORT DATE
November 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
John P. Woodyard
Howard L. Rishel

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
SCS Engineers
4014 Long Beach Boulevard
Long Beach, California 90807

10. PROGRAM ELEMENT NO.
C73DIC

11. CONTRACT/GRANT NO.
68-03-2471

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Sept 1976 to April 1980

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officers: Donald E. Sanning, (513) 684-7871
Oscar W. Albrecht, (513) 684-4216

16. ABSTRACT

In this report, the state of FGD acceptance in the utility industry is described. The various sludge treatment and disposal options are then delineated. Current federal and state regulations affecting FGD disposal are discussed, and then placed in a conceptual framework from which regulatory scenarios are developed. The scenarios are then applied to the current (1980) and projected (1985) FGD capacity to estimate what changes, if any, would need to be made in current utility operations to achieve compliance. Using the best available cost data base for these disposal alternatives, region-specific cost estimates are developed for 10 model power plants for each of five disposal options. Applying each regulatory scenario, the cost impact on the utility industry is then estimated for the 50 different situations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
flue gases desulfurization utility industry sludge disposal regulations cost estimates power plants	flue gas desulfurization sludge treatment cost data base FGD sludge disposal	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 135
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

TYPING GUIDE SHEET

PB81-118895

EPA-600/2-80-178
November 1980

THE COST OF ALTERNATIVE FLUE GAS DESULFURIZATION (FGD) SLUDGE DISPOSAL REGULATIONS

by

John P. Woodyard
Howard L. Rishel
SCS ENGINEERS
Long Beach, California 90807

Contract Number
68-03-2471

Project Officers

Donald E. Sanning
Oscar W. Albrecht
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
OUTSIDE DIMENSION FOR TABLES
BOTTOM OF IMAGE AREA, AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development constitute that necessary first step in a solution of the problem, and involve a definition of the problem, the measurement of its impact, and a search for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources; for the preservation and treatment of public drinking water supplies; and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents the technical cost impact analysis of several conceptual flue gas desulfurization (FGD) sludge disposal scenarios within the utility industry. The scenarios are structured to demonstrate the incremental cost of increasingly stringent technical requirements, and are not intended to parallel any proposed EPA regulations for FGD sludge disposal. The results provide a valuable tool to policy makers in both the regulatory agencies and utility industry.

FGD sludges have been classified as "special wastes" under Section 3004 of the proposed Resource Conservation and Recovery Act (RCRA) regulations. As such, a given sludge will be classified as either hazardous or nonhazardous according to the Section 3001 criteria, and its disposal will be regulated accordingly. Specific technical and administrative requirements for nonhazardous FGD sludge disposal have not been proposed, although final regulations under Section 4004 of RCRA apply to disposal of nonhazardous waste. The technical and economic impact assessments in support of specific disposal regulations for the utility industry are being contracted by EPA and should be completed by mid-1982.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory - Cincinnati

ABSTRACT

In this report, the state of FGD acceptance in the utility industry is described. The various sludge treatment and disposal options are then delineated. Current federal and state regulations affecting FGD sludge disposal are discussed, and then placed in a conceptual framework from which regulatory scenarios are developed. The scenarios are then applied to the current (1980) and projected (1985) FGD capacity to estimate what changes, if any, would need to be made in current utility operations to achieve compliance. Using the best available cost data base for these disposal alternatives, region-specific cost estimates are developed for 10 model power plants for each of five disposal options. Applying each regulatory scenario, the cost impact on the utility industry is then estimated for the 50 different situations.

This report was submitted in fulfillment of Contract No. 68-03-2471 by SCS Engineers under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1976 to April 1980.

CONTENTS

Disclaimer.....ii
Foreword.....iii
Abstract.....v
Figures.....ix
Tables.....x
Acknowledgements.....xv

1. Introduction.....1
    Purpose.....2
    Scope.....2

2. Conclusions.....4

3. Recommendations.....8

4. Profile of the Utility Industry and Its FGD Capacity.....10
    Introduction.....10
    History of utility industry.....10
    Utility power generation and sales.....11
    Environmental considerations in power generation.....12

5. The Technology Available for FGD Sludge Disposal.....16
    FGD sludge generation.....16
    FGD sludge treatment and disposal alternatives.....19

6. The Regulation of FGD Sludge.....39
    General.....39
    Clean Air Act and amendments.....39
    Federal Water Pollution Control Act (PL 92-500).....40
    Resource Conservation and Recovery Act of 1976 (PL 94-580).....40
    The Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532).....42
    Disposal to mines.....44
    State FGD disposal regulations.....46
    Regulatory scenarios discussions.....46

7. Development of Model Power Plants and Associated FGD Sludge Disposal Costs.....51
    Introduction.....51

CONTENTS (continued)

Model plant attributes....................51
Unit cost development....................58
Discussion of unit cost result....................63
Industry application of unit costs....................63

8. Utility Industry Response to Regulatory Scenarios....................73
Methodology and assumptions for the cost impact analysis....................73
Estimated industry response to more stringent regulations....................73
Cost impact of the utility industry response....................76

9. Analysis of Estimated Utility Industry Impacts....................110

References....................115

FIGURES

Number Page

1 Overview of available FGD sludge management options, including example ranges of sludge solids content....23

2 Description of IU Conversion Systems' Poz-O-Tec process for FGD sludge stabilization....31

3 Dravo process flow diagram showing three possible disposal options....33

4 Status of wet FGD sludge disposal....34

5 Trends in predominance of FGD sludge disposal practices among utilities....36

6 Alternatives for federal regulation of FGD sludge disposal under the Resource Conservation and Recovery Act....43

TABLES

Number		Page
1	Generating Capacity by Ownership for all Electric Utilities in the United States, 1970	10
2	Electrical Sales by Customer, 1970	11
3	United States Electrical Generating Capacity in Mid-1977	12
4	Existing and Projected Generating Capacity by Plant Type	13
5	Committed and Projected Nonregenerable FGD Capability, 1975-1985 (MW)	15
6	Estimated FGD Sludge and By-Product Production Rates for Coal-Fired Facilities	17
7	Examples of Typical Engineering Properties of FGD Sludge	20
8	Concentration of Constituents in Scrubber Liquors	21
9	Companies Providing Commercial Fixation or Disposal Service	29
10	Alternative Disposal Practices Available for Utility-Generated FGD Sludge	38
11	State Solid Waste Regulations Pertaining to Selected FGD Systems	47
12	Alternate Regulatory Scenarios for Flue Gas Cleaning Sludge Disposal	49
13	Manifestation of Regulatory Scenarios	50
14	Model Plant Location and Fuel Characteristics	52
15	Model Plant Regional Characteristics	53
16	Regional Land Prices	54

TABLES (continued)

Number		Page
17	Regional Construction Cost Indices	55
18	Operating and Maintenance Regional Cost Indices	56
19	Summary of Model Plant Attributes	57
20	Example Annual Revenue Requirements	59
21	Adaptation of TVA Conceptual Design Costs: An Example for Western Urban Unlined Ponding	61
22	Example of Model Plant Lifetime Revenue Commitments (in K$)	62
23	Estimated Capital Investment (K$) for All Model Utilities	64
24	Estimated Capital Investment ($/kW Capacity) for All Model Utilities	65
25	Estimated First-Year Operating Revenue Requirements (K$) for All Model Utilities	66
26	Estimated First-Year Operating Revenue Requirements (mills/kWh) for All Model Utilities	67
27	Estimated Total Lifetime Revenue Requirements (K$) for All Model Plants	68
28	Estimated Total Lifetime Revenue Requirements (mills/KwH) for All Model Plants	69
29	Estimated Present Value Lifetime Revenue Requirements (K$) for All Model Plants	70
30	Estimated Present Value Lifetime Revenue Requirements (mills/KwH) for All Model Plants	71
31	Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 1, 1980	74
32	Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 1, 1985	75
33	Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 2, 1980	77

TABLES (continued)

Number Page

34 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 3, 1980....................78

35 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 4, 1980....................79

36 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 5, 1980....................80

37 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 2, 1985....................81

38 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 3, 1985....................82

39 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 4, 1985....................83

40 Distribution of Utility FGD Sludge Disposal Capacity, Scenario No. 5, 1985....................84

41 Regulatory Scenario No. 1, Year 1980, Total Future Revenue Commitments........................85

42 Regulatory Scenario No. 2, Year 1980, Total Future Revenue Commitments........................86

43 Regulatory Scenario No. 3, Year 1980, Total Future Revenue Commitments........................87

44 Regulatory Scenario No. 4, Year 1980, Total Future Revenue Commitments........................88

45 Regulatory Scenario No. 5, Year 1980, Total Future Revenue Commitments........................89

46 Regulatory Scenario No. 1, Year 1985, Total Future Revenue Commitments........................90

47 Regulatory Scenario No. 2, Year 1985, Total Future Revenue Commitments........................91

48 Regulatory Scenario No. 3, Year 1985, Total Future Revenue Commitments........................92

49 Regulatory Scenario No. 4, Year 1985, Total Future Revenue Commitments........................93

TABLES (continued)

Number Page

50 Regulatory Scenario No. 5, Year 1985, Total Future Revenue Commitments....94

51 Regulatory Scenario No. 1, Year 1980, Total Capital Investments....95

52 Regulatory Scenario No. 2, Year 1980, Total Capital Investments....96

53 Regulatory Scenario No. 3, Year 1980, Total Capital Investments....97

54 Regulatory Scenario No. 4, Year 1980, Total Capital Investments....98

55 Regulatory Scenario No. 5, Year 1980, Total Capital Investments....99

56 Regulatory Scenario No. 1, Year 1985, Total Capital Investments....100

57 Regulatory Scenario No. 2, Year 1985, Total Capital Investments....101

58 Regulatory Scenario No. 3, Year 1985, Total Capital Investments....102

59 Regulatory Scenario No. 4, Year 1985, Total Capital Investments....103

60 Regulatory Scenario No. 5, Year 1985, Total Capital Investments....104

61 Regulatory Scenario No. 2, Year 1980, Total Displaced Capital Investments....105

62 Regulatory Scenario No. 3, Year 1980, Total Displaced Capital Investments....106

63 Regulatory Scenario No. 4, Year 1980, Total Displaced Capital Investments....107

64 Regulatory Scenario No. 5, Year 1980, Total Displaced Capital Investments....108

65 Summary of Regulatory Scenario Impacts for 1980....111

TABLES (continued)

Number Page

66 Summary of Regulatory Scenario Impacts for 1985..112

67 Summary of Regulatory Scenario Impacts to Consumers (mills/kWh)..........................114

ACKNOWLEDGEMENTS

This document is the result of an extensive technology review and cost analysis, based upon information produced as part of the EPA FGC waste disposal research program. The guidance and assistance provided by the Project Officers, Mr. Donald Sanning (technology) and Mr. Oscar Albrecht (economics), of the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, is gratefully acknowledged. Messrs. Julian Jones of IERL/RFP and Timothy Fields, John Heffelfinger, and Michael Shannon of OSW also made valuable contributions to the project.

Special thanks go to the industry review committee, who contributed their time and knowledge to the review of all major project outputs. Members of the committee are listed below:

- J. Wayne Barrier, Tennessee Valley Authority.
- James J. Crowe, Tennessee Valley Authority.
- Gary Merritt, Pennsylvania Department of Environmental Resources.
- Robert D. O'Hara, Duquesne Light Company.
- Randall Rush, Southern Company Services.
- Robert Van Ness, Louisville Gas and Electric.

SCS project participants were: Curtis J. Schmidt, Project Director; John P. Woodyard, Project Manager; Howard L. Rishel, Project Economist; and Brian West, Project Engineer.

The assistance of Howard W. Pifer and Robert L. Hayes, of Putnam, Hayes, and Bartlett, is also gratefully acknowledged.

SECTION 1

INTRODUCTION

The Clean Air Act (CAA) of 1970 and its amendments have placed air pollutant emission limits on a variety of stationary source categories. Under Subpart D of the regulation, emission standards were established for the sulfur oxides formed from the combustion of fossil fuels (specifically coal and oil) in steam electric power plants. The only commercially available means of meeting sulfur dioxide emission limits are by use of low-sulfur fuels or tail-end scrubbing of power plant flue gases to remove sulfur dioxide.

Vast reserves of low-sulfur coal are being mined in the Western United States for use by utilities nationwide. Many power plants in the Eastern and Western United States have nevertheless been retrofitted with tail-end flue gas desulfurization (FGD) systems due either to the rising price and high transportation cost of low-sulfur coal from the West, or to stringent state SO_2 emission regulations. The trend toward FGD was further reinforced by amendments to the CAA of 1977, which ultimately require FGD on all new coal-fired power plants.

Currently, the predominant technology for FGD is wet scrubbing with a lime-, limestone-, or sodium-based sorbent. A major drawback to this method involves disposal of large volumes of byproduct sludge. In 1973, the U.S. Court of Appeals remanded portions of the New Source Performance Standards (NSPS) for power plants to EPA for more information on FGD sludge disposal. EPA acknowledged the potential for adverse environmental effects from FGD sludge disposal, and recommended chemical fixation as the most acceptable method of treatment and disposal.

In order to further quantify potential environmental problems and identify possible solutions, EPA initiated a major research program in 1972, entitled, "Control of Waste and Water Pollution from Flue Gas Cleaning Systems." The five principal areas of investigation were as follows:

- Environmental assessment of FGD waste disposal.
- FGD waste disposal economics.
- Alternate disposal methods.
- FGD waste utilization.
- Power plant water use.

A 1977 report by SCS Engineers (25) summarized the FGD sludge disposal data base established thus far. The SCS study also recommended that any regulation of FGD sludge disposal be flexible enough to account for the effect of site- and sludge-specific variables on environmental impact potential.

The regulation of FGD sludge disposal to date has been performed on the state and local level through the interaction of solid waste, water quality, and other appropriate agencies. In the absence of specific federal guidance, the regulation of FGD sludge disposal has, by necessity, been site-specific. The promulgation of the Resource Conservation and Recovery Act (RCRA) of 1976, however, has posed the possibility of certain power plant wastes being defined as "hazardous." Should FGD sludge, in particular, be defined as a hazardous waste, sludge disposal operations would be subject to uniform stringent regulations for storage, handling, and disposal.

The physical and chemical properties of FGD sludges do, however, establish a need for regulation. The question of how to regulate FGD sludge still remains. Such management on the federal level could take a variety of forms, ranging from legislative control of state-permitting procedures to legislation and enforcement of minimum treatment and disposal requirements. Any approach which differs in severity from the current approach will have an associated economic impact on the utility industry.

PURPOSE

This study was initiated to assess the cost impacts of various degrees of hypothetical FGD sludge disposal regulations on the utility industry. It was noted in a previous study (25) that the potential environmental impact from waste disposal (in general) to land will vary according to many site-specific factors other than the waste characteristics. The specific purpose of this study is, therefore, to quantify the incremental cost of different degrees of regulation. The hypothetical regulatory scenarios presented in this report imply various degrees of environmental protection; however, it is not within the scope of this report to define the degree of environmental protection achieved by each of these scenarios.

SCOPE

The study was approached as a conceptual cost impact analysis rather than as a traditional economic impact analysis. Utilities electing to install wet FGD systems do so with the understanding that FGD sludge disposal will be an integral part of the FGD system. FGD sludge disposal typically accounts for 5 to 20 percent of the total annual cost of an FGD system (1). Recognizing the high cost and "emerging technology" status of sludge treatment and disposal, FGD has already been rejected by some utilities as an economically unacceptable technology. A more stringent FGD sludge disposal regulation need not, by itself, result in a major shift toward alternative desulfurization technologies.

In this report, the state of FGD acceptance in the utility industry is described. The various sludge treatment and disposal options are then delineated. Current federal and state regulations affecting FGD sludge disposal are discussed, and placed in a conceptual framework from which regulatory scenarios are developed. The scenarios are then applied to the current (1980) and projected (1985) FGD capacity to estimate what changes, if any, would need to be made in current utility operations to achieve compliance. Using the best available cost data base for these disposal alternatives (4), region-specific cost estimates are developed for 10 model power plants for each of five disposal options. Applying each regulatory scenario, the cost impact on the utility industry is then estimated for the 50 different situations.

SECTION 2

CONCLUSIONS

1. The CAA and its amendments have prompted the widespread implementation of wet FGD systems by utilities in an effort to meet sulfur dioxide emission limitations. This trend has been further enhanced by the current U.S. energy policy favoring the use of native coal reserves. The end result is a projected substantial increase in FGD implementation in the United States through 1985.

2. The predominant available FGD technologies generate large volumes of by-product sludges requiring disposal. These sludges have been and will continue to be disposed of to land, either to ponds as a slurry or to landfills as a dry material. Ponding is currently the most common method of FGD sludge disposal; sludge ponds are typically lined with in-situ soils, although synthetic and imported natural liners (particularly clay) have begun to find application. The disposal of treated and/or dewatered sludge to landfill is rapidly gaining favor, and should account for a majority of new sludge disposal capacity by the early 1980's. FGD sludge landfills are currently used to dispose of mechanically dewatered sludge, dewatered sludge mixed with dry ash, and chemically stabilized sludge.

3. The data base established thus far for FGD sludge indicates a need to regulate its disposal, primarily due to the potential for ground water contamination and land degradation (waste instability) resulting from the disposal of large volumes of this material to land. The regulation of FGD sludge disposal to date has been performed on the state level, typically involving state solid waste and water quality agencies in a site-specific permitting process.

4. The federal regulation of FGD sludge disposal is specifically considered. Current federal laws which may impact on the future regulation of FGD sludge disposal include the RCRA of 1976 (PL 94-580), the CAA amendments of 1977, the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532), the Federal Water Pollution Control Act (PL 92-500), and the Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87). The disposal of FGD sludge is specifically addressed only in RCRA.

5. The impact of federal FGD sludge disposal regulations on the utility industry would of course depend on the severity of the regulation. Recent research and current regulatory practice

indicate that ground water protection and the prevention of permanent land degradation are the principal environmental concerns when disposing of FGD sludge. The degree of protection which is necessary will be specific to each proposed disposal site.

In order to assess the cost impact of a range of regulatory approaches, a set of five regulatory scenarios was developed. Beginning with scenario No. 1, each scenario represents increasing severity of regulation based on (1) added protection of ground water and (2) added sludge stability for improved site reclamation potential, or (3) a universal requirement for sludge treatment and disposal regardless of site-specific factors. The five regulatory scenarios considered in this study are as follows:

No. 1. Federal Advisory-State Legislation and Enforcement: Simple permitting; stabilization not required and not commonly used.

No. 2. Federal Advisory-State Legislation and Enforcement: Site-specific evaluation with stabilization sometimes required.

No. 3. General Federal Legislation-State Enforcement: Physical stabilization required; no ponding.

No. 4. Comprehensive Federal Legislation-State Enforcement upon Approval: Chemical stabilization required in urban areas.

No. 5. Comprehensive Federal Legislation and Enforcement-No State Involvement: Chemical stabilization universally required; specifications given for the stabilization technique.

6. An accurate assessment of the cost impact of each scenario on the utility industry requires knowledge of the cost of each disposal alternative to each FGD-equipped plant. An approximation of these cost impacts was developed using a set of 10 model plants, representing three geographic regions, four coal types, and urban and rural locations. For each model plant, capital cost, annual operating cost, and lifetime revenue requirements were estimated for each of six disposal options. These disposal options were defined as follows:

- Unlined ponding.
- Clay-lined ponding.
- Dry (dewater) and landfill.
- Dravo.
- IUCS.
- Dry (dewater), mix, and landfill.

Each of the coal-fired utility generating plants projected to be on line by 1980 and 1985 was then assigned to one of the 10 model plant categories to produce an approximate industry profile of waste generating capacity. The profile was subjected to each regulatory scenario to estimate how each utility would shift from its preferred disposal option to its remaining least-cost disposal option under the revised regulatory scenario. In this manner, the cost impacts to each utility and to the industry as a whole were estimated as the incremental cost of complying with each successive degree of regulation.

It should be emphasized that this approach includes only plants that will be on line by mid-1980, or those that will be on line by mid-1985. Although cost impacts were estimated for the entire remaining life span of each of these plants, a declining operating scenario was used in which annual generation decreases over the life span of each plant. Thus, the plants in the 1980 group included substantially more retrofit situations than for the predominantly younger 1985 group of plants. The result of this shift in group composition is a substantial increase in total remaining lifetime generation, even though coal-fired generation capacity is expected to increase only moderately between 1980 and 1985.

7. From Section 8, it appears that, in the absence of additional regulatory constraints, the utility industry from a post-1980 perspective will be committed to spending close to $2.6 billion (1980 dollars), and from a post-1985 perspective will be committed to spending over $3.1 billion (1980 dollars) for FGD sludge disposal. Scenarios No. 2 through 5 are expected to add from $18 to $972 million to those future revenue commitments for the post-1980 estimate, and from $35 to $2,324 million for the post-1985 estimate. This relatively modest increase in future revenue commitments is due to two factors: (1) older plants using high-technology retrofits will be 5 years older by 1985, so that their post-1985 revenue commitments will be substantially reduced; and (2) new plants coming on line by 1985 will have their entire useful life ahead of them; they will be situated on cheaper, rural land, and will have selected the cheaper, nonretrofit disposal options as part of their original designs.

This post-1980 to post-1985 shift in future generation to newer plants (combined with an absolute increase in future coal-fired generation) allows the average cost per kilowatt hour (in terms of 1980 dollars) to decrease. The result is that the average future cost (1980 dollars) to the consumer for FGD sludge disposal is expected to range from 1.017 mills (scenario No. 1) to 1.400 mills (scenario No. 5) per kilowatt hour after 1980, and from 0.759 (scenario No. 1) to 1.321 (scenario No. 5) mills per kilowatt hour after 1985. It should be emphasized again that these cost estimates do not include plants coming on line after 1985.

8. In general, more stringent disposal regulation resulted in (1) lower per unit capital requirements than for current disposal practices, and (2) higher lifetime revenue requirements as a result of higher operating costs (labor and raw materials in particular).

9. The industry profile for 1980 shows that sludge ponding is more prevalent in the western United States than in the East, due in most cases to more favorable site-specific conditions. The cost impact of more stringent regulatory scenarios (particularly the universal stabilization requirement) in the West was proportionately greater than for the Midwest or East.

SECTION 3

RECOMMENDATIONS

Research recommendations resulting from this study may be categorized into two general areas: (1) incorporating the diversity of local utility conditions into the analysis, and (2) updating the current data base to reflect changes in the regulatory climate and the evolution of FGD technologies.

With regard to the first area, the conceptual nature of this study required the use of many simplifying assumptions. As a result, important cost factors were not accounted for which could significantly affect the costs projected in this study. Candidates for inclusion in a more in-depth analysis include the following characteristics:

- Local administrative overhead rates.
- Local debt/equity ratios.
- Local interest/return to equity rates.
- Effective income tax rates.
- Local real estate tax rates.
- Local land cost.
- Local construction cost differentials.
- Local operating cost differentials.
- Local fuel characteristics.
- Local regulatory climate.

In addition to addressing these factors on a local rather than a regional basis, any subsequent research embracing these plant-by-plant variations should also consider the effects that current sludge disposal capital investments and remaining plant lives have on the selection of either a sludge disposal method or a compliance strategy for sulfur oxide control. In this study, sunk capital costs and remaining plant life span were not allowed to influence this choice, as they would in practice.

Also, in this study, life cycle average unit costs per kilowatt hour of generation for a new 500-MW plant were applied to plants of all sizes and ages. Such simplifying assumptions should be avoided in a more extensive analysis of economic impact. Use of FGD sludge disposal cost estimates for actual systems will also allow for individual plant-scale economies, and make more precise allowance for the impact that the remaining plant operating life has on sludge disposal land requirements.

Another topic of possible interest to EPA, which could not be explored in this study, is the important interrelationship between sludge disposal costs, electricity rate schedules, subsequent changes in electricity demand, and the ultimate incidence (by customer type) of FGD sludge disposal costs. To expedite the analysis, it was assumed that electricity demand was perfectly inelastic with respect to price changes, and that sludge disposal costs became revenue requirements for the same year in which they were incurred. Although this approach is appropriate for a first approximation of regulatory impacts, the pricing and demand mechanisms deserve additional consideration. Sludge disposal costs may be lagged over time and have differential impacts on various classes of customers. Moreover, demand elasticity may vary by customer class. The distribution of FGD sludge disposal costs will require additional evaluation before the impacts on various classes of consumer can be adequately determined.

The other general area which deserves additional study is the rapid evolution of FGD sludge disposal technology in response to the changing regulatory climate, and its resulting cost impact on the utility industry. Ongoing field research by EPA will further enhance the current sludge disposal data base. EPA guidelines possibly resulting from this research, may lead to the development of regulatory scenarios which could not be anticipated here. Dry FGD technologies (spray dryers and dry injection) are also gaining utility acceptance, and provide one more option for compliance with both air and solid waste regulation.

Specific areas which could be enhanced in an update of this study include:

- Second-generation FGD sludge disposal technologies.
- Trends in FGD.
- Updated forecasts of FGD implementation.
- Long-range utility power generation trends.
- Impact of RCRA and MSAA on FGD sludge management.

Consideration of the above-named technical and institutional changes, combined with a more exact analysis of disposal economics, would provide a solid foundation for the economic impact analysis required in conjunction with impending new federal regulations for FGD sludge disposal.

SECTION 4

PROFILE OF THE UTILITY INDUSTRY AND ITS FGD CAPACITY

INTRODUCTION

Electric utilities provide for the generation, transmission, and distribution of electric power. Ownership of utilities is characterized by two distinct owner categories: publicly owned and privately owned (investor). Publicly owned systems can be cooperatives, or can be owned by municipal or federal agencies, or others. Not all of the more than 3,300 utilities in the United States provide all three services mentioned above. Only about 1,000 larger utilities carry out generation operations. Many smaller utilities instead purchase power from generators for distribution to their customers. Many utilities have also entered into pools with adjacent systems to provide energy to one another under heavy load or emergency conditions.

HISTORY OF UTILITY INDUSTRY

The first utility system was established on line in 1880 with the completion of Thomas Edison's steam electric power plant in New York City. The industry experienced consistent but restricted growth for the next half-century because of limited energy demand. After World War II, consumer demand for electricity began to increase dramatically. Since then, per capita electrical consumption has grown at an annual rate of 6 percent, and total electrical consumption at an annual rate of 7 percent. By 1977, total U.S. generating capacity was 545,364 MW. The table below summarizes generating capacity by ownership types as of 1970 (28).

TABLE 1. GENERATING CAPACITY BY OWNERSHIP FOR ALL ELECTRIC UTILITIES IN THE UNITED STATES, 1970

Ownership	Number of Systems	Percent	Generating Capacity (MWx10^6)	Generating Capacity Percent	Annual Generation (MWx10^6)	Annual Generation Percent
Investor	250	24.6	265	76.8	1,180	77.0
Federal	2	0.4	40	11.6	190	12.4

TABLE 1 (continued)

Ownership	Number of Systems	Percent	Generating Capacity (MWx10^6)	Generating Capacity Percent	Annual Generation (MWx10^6)	Annual Generation Percent
Public	700	68.6	35	10.1	140	9.1
Co-op	65	6.4	5	1.5	22	1.5
Total	1,017	100.0	345	100.0	1,532	100.0

UTILITY POWER GENERATION AND SALES

The electric utility industry is limited to the production and delivery of one product: electricity. Electrical power can not be practically stored, yet utilities must be capable of meeting consumer demand at any time. The capability to meet consumer needs on demand is, therefore, the design parameter upon which generating capacity is based. Except for a small fraction of customers with interruptable service, the most important factor in utility performance is meeting peak consumer demand.

Utility customers can be divided into industrial, commercial, and residential categories. Table 2 compares the electrical consumption of these customers in 1970 (28).

TABLE 2. ELECTRICAL SALES BY CUSTOMER, 1970

Customers	Number of Customers (x10^6)	Annual Sales (MW x 10^6)	Percent of Total*
Industrial	0.4	575	41
Commercial	8	325	18
Residential	55	450	24
Other	--	60	17

* The Federal Energy Regulatory Commission (FERC) reports no expected change in the above distribution of sales through 1990 (28).

Utilities exist either as public services or as regulated monopolies. As a provider of a public service, a utility is obligated to supply its product to all customers in its service area. Additionally, its rate structure must offer customers within each class (i.e., industrial, commercial, and residential) equal service at equal cost. Utilities are protected against competition. However, they cannot discontinue unprofitable operations within their service area. Both the level of service and the rates charged for that service are subject to regulation by both state and federal agencies. Utility expenses are closely monitored by regulating commissions to determine rates for each class of service. Except for fuel clauses that allow utilities to immediately pass along increases in fuel costs in the form of higher rates, the industry is limited to regularly scheduled hearings (e.g., every 6 months), when rate increases can be approved. Demand for electric power is relatively "inelastic" with respect to utility rates because customers (particularly residential) have few suitable alternatives.

Fossil fuel-fired electric power plants accounted for 77 percent of total U.S. generating capacity and 81 percent of total power generated in mid-1977. Table 3 presents a breakdown of generating capacity by fuel type.

TABLE 3. UNITED STATES ELECTRICAL GENERATING CAPACITY IN MID-1977 (7)

Fuel	Percent of Capacity
Coal	38
Oil	25
Gas	14
Nuclear	9
Hydro	12
Other	4

Coal is the most abundant fossil fuel in the United States. Proven reserves are estimated to be sufficient to supply fossil fuel needs for 200 to 300 years. Before 1973, government projections indicated a future decrease in coal-fueled utility power generation. Since that time, oil price increases and nuclear plant construction blockages have resulted in revised projections indicating substantial increases in coal generation capacity. Total electric power generation is expected to increase by 100 percent between 1980 and 1990 (28). Table 4, which presents electric generating capacity projections based on more recent (1977) FEA data (7), shows an estimated 72 percent increase between 1977 and 1995.

ENVIRONMENTAL CONSIDERATIONS IN POWER GENERATION

The production of both natural gas and low-sulfur oil (from domestic sources) has been declining for several years. Natural

TABLE 4. EXISTING AND PROJECTED GENERATING CAPACITY BY PLANT TYPE*

	Existing (1977)		Projected New Capacity (1995)		Total	
Plant Type	Capacity (MW)	Percent of Total	Capacity (MW)	Percent of Total	Capacity (MW)	Percent of Total
Coal	206,258	38	148,739	38	354,997	38
Oil	134,615	25	25,093	6	159,708	17
Gas	75,548	14	1,919	.5	77,467	8
Nuclear	48,697	9	174,189	45	222,886	24
Hydro	66,817	12	26,999	7	93,816	10
Other	3,867	1	1,933	.5	5,800	1
Unknown	9,562	2	11,722	3	21,284	2
Total	545,364	100	390,594	100	935,958	100

*Ref. 7

gas availability in particular has been limited since the late 1960's, resulting in a major industry switch to oil in previously gas-fired power plants. Subsequent increases in the cost of fuel oil from foreign sources have made coal and nuclear power more attractive near-term energy sources for most utilities.

Coal combustion produces greater volumes of air pollutant emissions than natural gas or fuel oil combustion. Particulate, sulfur oxide, and nitrogen oxide emission limits were established by the CAA of 1970 and its amendments. The control technology for particulates is considered adequate to meet those emission limits. Combinations of cyclone separators and electrostatic precipitators (ESP's) are the most common control strategies used, achieving particulate collection efficiencies in excess of 99 percent. Fabric filters and wet scrubbers are also gaining acceptance for utility control of particulate emissions.

The choice of control strategies for sulfur oxides is limited to the use of scarce and costly low-sulfur fuels, conversion of the coal to a cleaner fuel (either through gasification or physical/chemical coal-cleaning), and/or tail-end removal of sulfur oxides from the exhaust gas. The selection of the first alternative alone may not be acceptable as a means of long-term compliance with emission limits. Physical coal cleaning, although capable of removing a significant percentage of pyritic (inorganic) sulfur from most coal supplies, cannot generally remove sufficient sulfur to meet NSPS, but may allow reductions to meet State Implementation Plans (SIP), or can be used in combination with FGD. Chemical coal-cleaning is in its infancy on the utility scale. Tail-end wet scrubbing of SO_2 has by necessity gained acceptance among utilities.

The vast majority of scrubber systems installed to date are of the nonregenerable variety. These systems produce a slurry from which only the liquid fraction may be recycled; a portion of the fraction is continuously purged and disposed of. As of June 1977, 28 operational FGD units had been installed on utility scale boilers in the United States. Table 5 displays projected FGD capability through the year 1985, based on available information. As shown in the sixth column, approximately 26,000 MW of generating capacity is presently committed to use of FGD systems by 1985. In addition, approximately 74,000 MW of generating capacity is being considered for FGD systems.

TABLE 5. COMMITTED AND PROJECTED NONREGENERABLE FGD CAPABILITY, 1975-1985 (MW)*

	Lime Scrubbing	Limestone Scrubbing	Lime/ Limestone	Double Alkali	Total Committed	Total Projected
1975†	475 (2)	1,954 (9)	20 (2)	32 (1)	2,481 (14)	----
1980†	9,445 (23)	12,695 (35)	270 (3)	902 (4)	23,312 (65)	35,000
1985†	11,515 (28)	13,445 (37)	797 (4)	#	26,659 (73)	100,000

~~*Ref 16~~

---

[*] Ref. 16.

[†] Numbers in parenthesis indicate number of scrubber units.

[#] None committed beyond 1980.

SECTION 5

THE TECHNOLOGY AVAILABLE FOR FGD SLUDGE DISPOSAL

FGD SLUDGE GENERATION

Virtually all FGD systems are designed to react sulfur oxide gases with selected solid or dissolved sorbents to form a residue suitable for treatment, reuse, and/or disposal to land. Since the promulgation of the CAA in 1970, wet scrubbing systems which use dissolved lime or limestone as the sorbent have been the predominant method of FGD. Reaction of sulfur oxide with lime or limestone in the scrubber results in the formation of calcium sulfate and sulfite precipitates, which are separated from the liquid portion through settling and filtration. The liquid portion is then mixed with additional lime or limestone and reused in the scrubber; the separated solids are removed for disposal.

FGD Sludge Generation Rate

The rate at which the sludge is generated is a function of several factors. The principal factor determining the quantity of solid material generated is the sulfur content of the coal; the rate of sulfur oxide generation dictates the stoichiometric requirements of sorbent addition to the scrubber. The total weight of sludge solids will vary slightly according to the sulfur oxide collection efficiency, the efficiency of lime or limestone utilization, and the level of sulfite oxidation in the scrubber system. In systems where the FGD system is not preceded by an ESP, the amount of fly ash collected by the scrubber must also be taken into account.

Table 6 presents general sludge emission factors for commercially available FGD systems. The generic emission factor equation presented for limestone, lime, and double alkali (sodium) systems was developed from empirical data, and is not sensitive to changes in collection efficiency or sulfite oxidation level. The adjustments shown in the table represent some form of treatment through addition; the additive rate is reflected in the adjustment factor. The treatment processes will be described in more detail later in this chapter.

TABLE 6 . ESTIMATED FGD SLUDGE AND BY-PRODUCT PRODUCTION RATES FOR COAL-FIRED FACILITIES

		Adjustments			
Scrubbing Process	By-Product Generation Rate*	Co-collection with Flyash	Dravo Treatment	IUCS Treatment	Remarks
Limestone	23.5 S + .17 A^2 + 104+	x 1.53	x 1.03 x 1.05 #	x 1.04	+ .87 for lime scrubbing and double alkali
Sodium carbonate	12.0 gal/MW/hr (no data available on solids in waste)				Partial recycle
Magnesium oxide	4.56 gal/MW/hr (no data available on solids in waste)	1.42 lb/ MG/hr	--	--	By-product not intended to be waste
Wellman-Lord	5.45 lb/MW/hr (solids)	2.7 lb/ MW/hr	--	--	By-product not intended to be waste

* A = Ash content of coal, percent.

+ S = Sulfur content of coal, percent, at assumed SO_2 removal efficiency of 90 percent.

# Computed from empirical data, lb/MW/hr, in cases where flyash is collected with SO_2.

Physical and Chemical Properties

The physical and chemical properties of FGD sludge are affected by many variables inherent in the operation of the scrubber and power plant. These variables include the following:

- Characteristics of the fuel burned.
- Combustion equipment and operating parameters.
- Particulate collection mode.
- Scrubber operating parameters (liquid/gas ratio, slurry retention time, recirculation ratio, etc.).
- FGD reagent and input water quality.
- Type of sludge treatment employed.

Both the physical and chemical properties of FGD sludge have been the subject of extensive research. The reader is referred to the literature (8, 11, 17, 25, 26) for the detailed findings of these research efforts.

The data which is of particular interest to this study is that which relates to the environmental impact (and the associated regulation) of FGD sludge disposal. The two principal environmental concerns when disposing of FGD sludge to land are (1) the potential for ground water and surface water contamination from contact with soluble sludge constituents, and (2) the potential for land degradation from the disposal of large volumes of unstable material. Research to date has therefore concentrated on identifying the chemical composition and engineering properties of both treated and untreated FGD sludge.

The by-products of nonregenerable FGD systems are typically composed of four major solid constituents: calcium sulfate hemihydrate and/or dihydrate (due to mixed crystallization), calcium sulfite hemihydrate, unreacted sorbent, and fly ash. The relative amounts of these constituents are determined by the various scrubber and power plant operating parameters discussed previously.

The physical properties of FGD sludge which are of primary concern during treatment and disposal are permeability, bulk density, compaction strength, and viscosity. These properties are determined to a great extent by the crystal morphology and moisture content of the sludge. Crystal morphology will vary between the major solid phases; as a result, physical properties vary according to the relative percentage of calcium sulfate, sulfite, and carbonate solids and fly ash present. Crystal structure will also control the limit to which the sludge can be dewatered by a given operation. Moisture content is a key factor in determining the rate of contaminant mass transport to the surrounding environment, as well as the viscosity and load bearing strength of partially dewatered sludge.

Some physical properties of FGD sludge can be predicted based on information about crystal morphology and moisture content using the data base established thus far. When these properties are not adequate, further treatment may be desirable to aid in sludge management or comply with regulatory guidelines. Table 7 presents some typical values for the engineering properties of FGD sludge.

The solid phase of FGD sludge can also contain a variety of trace metals. Trace metals can originate from several sources, including fly ash (collected with SO_2 or added to the sludge), sorbent, and make-up water or vapors collected from the flue gas itself. The trace metals contained in fly ash, their principal source, generally remain in the solid phase. Those which form on the ash surface can be dissolved in the waste slurry and enter the liquid phase; from there, they may either precipitate as pure compounds, such as sulfate/sulfite crystals, or else remain in solution.

The characteristics of the liquid phase are important due to its potential as a mass transport medium for trace contaminants. FGD sludge liquors typically contain ions of sulfate, sulfite, chloride, calcium, magnesium, and various trace chemical species. The total dissolved solids (TDS) concentration in FGD sludge is a function of chemical operating conditions in the scrubber system, with TDS concentration in excess of 20,000 ppm being quite common in some systems. Table 8 displays a range of contaminant concentrations in FGD sludge liquors and elutriates, based on the results of a variety of extraction procedures.

FGD SLUDGE TREATMENT AND DISPOSAL ALTERNATIVES

Utilities equipped with wet scrubbing FGD systems can dispose of the by-product sludge in one of three ways: ponding, landfilling, or sale for reuse. The latter alternative is not considered viable in the near term due to limited market demand for sludge by-products (gypsum, road-base material, etc.). Ultimate disposal methods of ponding and landfilling are therefore expected to predominate through 1990.

Within the general pond and landfill disposal methods are several variations based upon the type of sludge treatment employed. These variations, displayed graphically in Figure 1, are composed of one or more of the following attributes:

- The disposal site is lined with a synthetic or other non-native liner material.

TABLE 7. EXAMPLES OF TYPICAL ENGINEERING PROPERTIES OF FGD SLUDGE[*]

	Predominant Solid Species	
Property/Characteristic	$CaSO_4 \cdot 2H_2O$	$CaSO_3 \cdot 1/2H_2O$
Crystal morphology	Tetrahedral	Plate-like and/or spherical aggregate
Moisture content:		
• Settled	50-65%	25-40%
• Centrifuged	55-75%	40-60%
• Filtered	60-80%	45-60%
Bulk density[†]	1.5-1.9 gm/cc	1.2-1.8 g/cc
Permeability[#]	10^{-3}-10^{-6} cm/sec	10^{-3}-10^{-5} cm/sec
Compressive strength	2.0 x 10^6 dynes/cm^2 @ 35% moisture	2.4 x 10^6 dynes/cm^2 @ 30% moisture
Viscosity	10 cp @ 38.5% moisture 46 cp @ 36.5% moisture	120 cp @ 40% moisture 20 cp @ 50% moisture

[*] Ref. 9.
[†] Ref. 11, function of moisture content.
[#] Will vary with compaction and dewatering.

TABLE 8. CONCENTRATION OF CONSTITUENTS IN SCRUBBER LIQUORS*

	Range of Constituent Concentrations at Potential Discharge Points	
Constituents	Mg/l (Except pH)	M
Aluminum	0.03 - 0.3	$10^{-5.95}-10^{-4.95}$
Antimony	0.09 - 2.3	$10^{-6.13}-10^{-4.72}$
Arsenic	<0.004 - 0.3	$<10^{-7.27}-10^{-5.40}$
Beryllium	<0.002 - 0.14	$<10^{-6.65}-10^{-4.81}$
Boron	8.0 - 46	$10^{-3.13}-10^{-2.37}$
Cadmium	0.004 - 0.11	$10^{-7.44}-10^{-6.01}$
Calcium	520 -3,000	$10^{-1.89}-10^{-1.12}$
Chromium (total)	0.01 - 0.5	$10^{-6.72}-10^{-5.02}$
Cobalt	0.10 - 0.7	$10^{-5.77}-10^{-4.92}$
Copper	<0.002 - 0.2	$<10^{-7.50}-10^{-5.50}$
Iron	0.02 - 8.1	$10^{-6.45}-10^{-3.84}$
Lead	0.01 - 0.4	$10^{-7.32}-10^{-5.71}$
Magnesium	3.0 -2,750	$10^{-3.91}-10^{-0.95}$
Manganese	0.09 - 2.5	$10^{-5.79}-10^{-4.34}$
Mercury	0.0004- 0.07	$10^{-8.70}-10^{-6.46}$
Molybdenum	0.91 - 6.3	$10^{-4.71}-10^{-4.18}$
Nickel	0.05 - 1.5	$10^{-6.07}-10^{-4.59}$
Potassium	5.9 - 32	$10^{-3.82}-10^{-3.09}$
Selenium	< 0.001 - 2.2	$< 10^{-7.90}-10^{-4.56}$
Silicon	0.2 - 3.3	$10^{-5.15}-10^{-3.93}$

TABLE 8 (Continued)

Constituents	Range of Constituent Concentrations at Potential Discharge Points	
	Mg/l (Except pH)	M
Silver	0.005 - 0.6	$10^{-7.33}-10^{-5.25}$
Sodium	14 -2,400	$10^{-3.21}-10^{-0.98}$
Tin	3.1 - 3.5	$10^{-4.58}-10^{-4.53}$
Vanadium	<0.001 - 0.67	$<10^{-7.71}-10^{-4.88}$
Zinc	0.01 - 0.35	$10^{-6.82}-10^{-5.27}$
Carbonate	41 - 150 (as $CaCO_3$)	$10^{-3.39}-10^{-2.82}$
Chloride	420 -4,800	$10^{-1.93}-10^{-0.87}$
Fluoride	0.07 - 10	$10^{-5.43}-10^{-3.28}$
Sulfite	0.8 -3,500	$10^{-5.00}-10^{-1.36}$
Sulfate	720 -10,000	$10^{-2.12}-10^{-0.98}$
Phosphate	0.03 - 0.41	$10^{-6.50}-10^{-5.36}$
pH	3.04 - 10.7	$10^{-3.04}-10^{-10.7}$
Ionic strength		0.05 - 0.80

---

* Ref. 17.

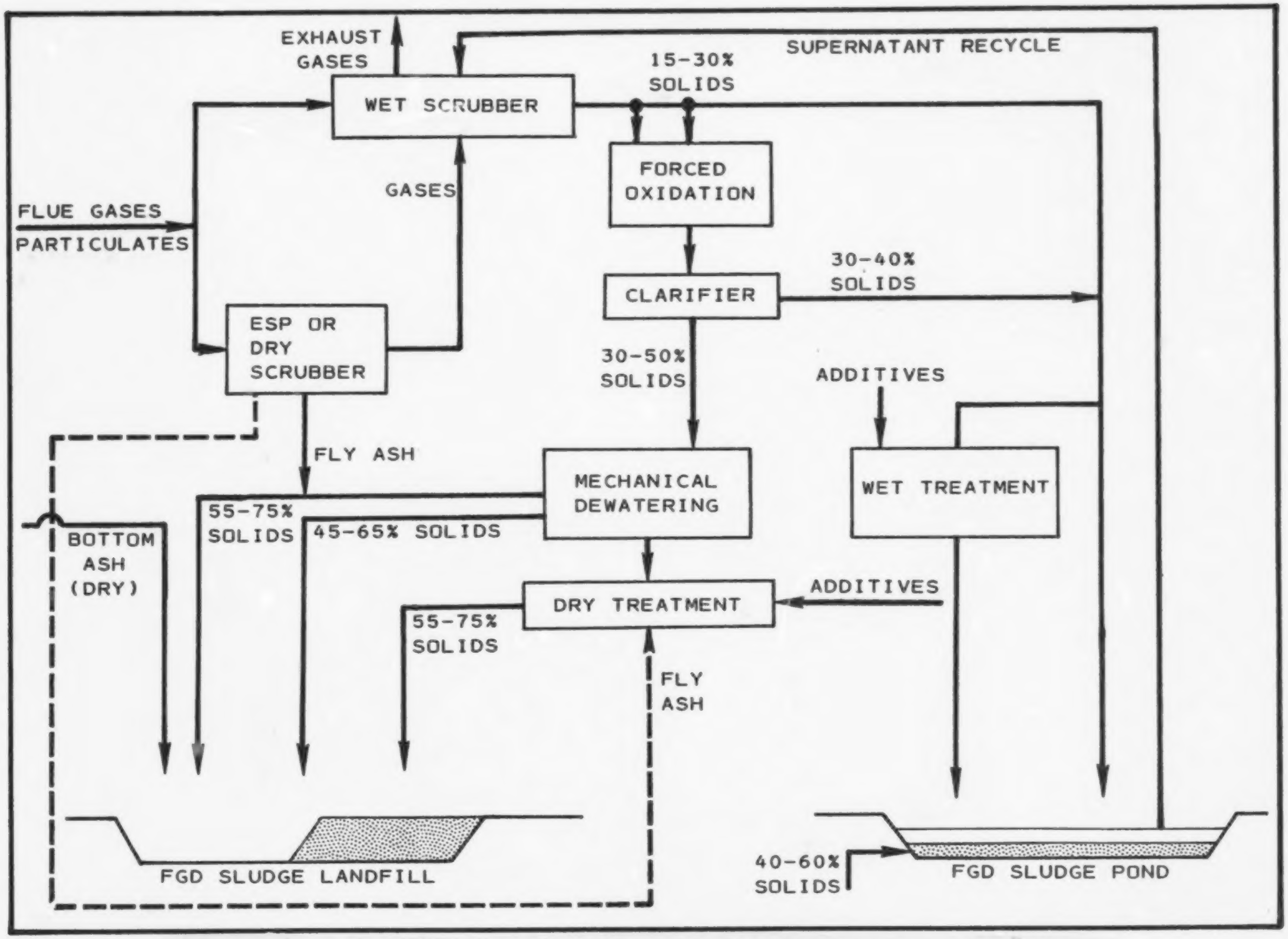
EXHAUST
GASES
SUPERNATANT RECYCLE
WET SCRUBBER
15-30%
SOLIDS
FLUE GASES
PARTICULATES
GASES
FORCED
OXIDATION
CLARIFIER
30-40%
SOLIDS
ESP OR
DRY
SCRUBBER
30-50%
SOLIDS
ADDITIVES
FLY ASH
MECHANICAL
DEWATERING
WET TREATMENT
55-75%
SOLIDS
45-65% SOLIDS
BOTTOM
ASH
(DRY)
DRY TREATMENT
ADDITIVES
55-75%
SOLIDS
FLY
ASH
FGD SLUDGE LANDFILL
40-60%
SOLIDS
FGD SLUDGE POND

Figure 1. Overview of available FGD sludge management options, including example ranges of sludge solids content.

- The sludge is mechanically dewatered to improve its handling properties and enhance disposal site reclamation potential.

- The slurried or dewatered sludge is mixed with other materials to form a stable material with predictable engineering properties and environmental impact.

The selection of a sludge treatment and disposal system is predicated upon the need for (1) site reclamation and (2) ground water protection. The former need may be dictated solely by economics, while the latter is based upon design criteria put forth by the applicable regulatory agency.

To date, utility scale FGD sludge management is being performed using the following treatment and disposal combinations:

- Disposal of clarifier underflow to ponds which have acceptable in-situ soils as liners.

- Disposal of clarifier underflow to lined ponds (synthetic or imported clay liners).

- Disposal of mechanically dewatered sludge to landfill.

- Admixing of lime and fly ash with sludge, and disposal to landfill.

- Commercial stabilization (controlled admixing of fixative materials to sludge) and disposal to landfill.

These five generic disposal systems are employed in the cost impact analysis. The following is a brief discussion of the conceptual disposal systems. A more detailed description of these systems and their variations is presented in the literature (4, 13, 25).

Ponding of FGD Sludge

FGD sludge ponds typically require embankments, although some pond designs have employed such topographical features as pond sides. Sludge ponds usually vary from 20 to 40 feet in depth, including the settled sludge and supernatant. At this depth, a power plant will fill 0.6 to 0.75 acres of land for every megawatt of capacity during its 30-year life.

Sludge ponds receive material in one of three forms:

- A 10 to 20 percent solids slurry directly from the scrubber system.

- A 30 to 45 percent solids underflow from a clarifier.

- A slurry of stabilized sludge and scrubber liquor.

In some instances, ponds of the above variety also serve as settling basins. Supernatant is recirculated as scrubber make-up water.

FGD sludge pond design must provide an effective barrier to prevent contaminant migration from the site. Disposal sites are often selected so that their in-situ soils provide such a natural barrier. When no such site can be found within reasonable proximity to the power plant, nonnative liner materials may be employed. Clay, asphalt, cement, rubber, and plastic have served as liners in various waste disposal applications. The associated high cost has severely limited their application in the utility industry.

Dewatering and Disposal to Landfill

Mechanical dewatering of FGD sludge will produce a semicohesive material which can be trucked to and placed in a landfill. No additives are employed to improve handling characteristics or decrease permeability.

Scrubber effluent typically contains about 15 percent solids. In order that sludge can be transported and placed in a landfill, a much higher solids content must be attained. Thickening the sludge from 15 to 60 percent solids generally takes place in two steps.

Primary dewatering usually takes place in a clarifier. Clarifiers (also referred to as settling tanks and gravity thickeners) are a standard unit treatment process on most full-scale scrubber sludge treatment installations. In addition to dewatering clarifiers sometimes function as mixing or preparation basins for recirculated scrubber feedwater.

Clarifier design is based primarily on the settling characteristics of the sludge, which in turn are largely dictated by sludge constituents and particle size. Scrubber sludges, especially those generated by lime or limestone processes, exhibit fair settling characteristics compared to most solids encountered in the chemical processing industry. Clarification results in a sludge having between 35 to 45 percent solids.

Secondary dewatering in FGD sludge treatment may be accomplished by a variety of equipment. Dewatering processes with demonstrated or potential applicability to scrubber sludges are:

- Centrifuges.
- Vacuum filters.
- Solar evaporation ponds.
- Bed dryers.
- Thermal dryers.

The first three processes listed above have been applied to scrubber sludges, and operating experience is documented. The other processes listed have not been applied to scrubber sludges, but have been used successfully for other types of industrial and municipal sewage sludges.

The use of centrifuges for sludge dewatering has had laboratory and pilot-scale analysis in the United States, and widespread use in Japan. Centrifugation is an efficient technique for removing unbound moisture from wetted solids; however, it entails comparatively high power consumption and maintenance requirements.

Several centrifuges are available commercially, differing primarily in the design of the collection surface and the feed and discharge mechanisms. Bowl-type centrifuges have been applied to scrubber sludges.

The vacuum filter process appears to be the best secondary dewatering technique for most FGD sludges. Both the revolving drum and belt filter designs yield better overall performance (when reliability is considered) than the centrifuge. Like other dewatering methods, however, process effectiveness is highly dependent on sludge characteristics, and is subject to operating difficulties.

Sludge variables that are known to affect filter performance are concentration and nature of solids, viscosity, temperature, and compressive strength. Operating variables are vacuum strength, filter media, drum speed, degree of drum submergence, and amount of fluid agitation. Problems encountered include cake cracking and difficulties with cake removal from the filter media, both of which have resulted in temporary shutdown of experiments.

In dewater-and-landfill operations, sludge clarifier underflow is conveyed by pipe to the secondary dewatering system (usually a drum filter). The filter cake is then transported by truck or conveyor to the landfill site. Placement equipment is usually limited to bulldozers and similar tractors.

Lime/Fly Ash Admixing

The fixation processes described in the previous section involve admixing of various materials with scrubber sludge in a predetermined proportion, to obtain predictable physical and chemical properties. The admixture ratios have been developed as a result of years of research, and represent the optimal conditions under which selected chemical reactions take place. Because the minimum acceptable physical properties will be specific to each application, it is possible that adequate strength can be obtained using other, less sophisticated methods of treatment and admixing.

The addition of lime to anhydrous silica and aluminosilicate, as is found in fly ash, produces a pozzolanic reaction resulting in calcium silicate or aluminate gels. The product is a cementitious material. This reaction, which is common to such materials as portland cement, is also the basis of most commercial stabilization processes. The process ingredients include either natural or synthetic pozzolans.

Fly ash is a natural pozzolan, and can be used with free lime, present in the sludge, or with the addition of lime to stabilize FGD sludge. Studies by Weeter (26) and others have documented the relationship between admix proportions and resultant physical properties. The relationship between the lime/fly ash ratio and such properties as compressive strength, settling velocity, filterability, shear stress, cohesion, bulk density, and permeability are documented (8, 9, 13, 26). Overall, lime/fly ash stabilization appears to greatly enhance many of these properties with regard to disposal mechanics and environmental impact.

Treatment of FGD sludge using lime and fly ash is accomplished simply by dewatering the sludge using a vacuum filter or centrifuge, and subsequently blending appropriate amounts of lime and dry fly ash in a mixer. The material is, at that point, sufficiently stable for truck transport to a landfill. Lime is typically added on the basis of the fly ash addition rate. Fly ash addition is, in turn, based upon the quantity required to achieve optimum moisture content in the dewatered sludge. The amount of fly ash available will, of course, depend on the nature of the combustion facility and the type of coal burned.

The advantages of lime/fly ash admixing are numerous. It is perhaps the lowest cost method of stabilization available. Mixing fly ash with the sludge, with or without the addition of lime, may result in some stabilizing reactions due to available free lime, or will simply increase the solids content for easier handling. The use of power plant wastes, such as fly ash and bottom ash, as an admix with scrubber sludge also reduces the number of solid waste streams to be handled separately.

Chemical Stabilization of FGD Sludge

There is a trend among utilities and regulatory agencies to favor dry disposal of FGD wastes. While many utilities employ simple mechanical dewatering and/or ash admixing to achieve the desired product, still others have contracted with commercial services for operation of the disposal system and use of their proprietary admix process.

Chemical stabilization, or "fixation," as it is often referred to, is designed to provide a predictable improvement in sludge physical or chemical properties. In no instance do fixation processes for FGD sludge attempt to remove contaminants from the sludge.

A variety of fixation processes are commercially available. Table 9 lists most of these fixation processes and services, along with a summary of their experience with FGD sludge. More detailed descriptions of each process are available in the literature (13).

Of the 16 processes referred to in the table, only Dravo and IU Conversion Systems, Inc. (IUCS) have long-term, full-scale experience treating FGD sludge. These two processes are described in more detail on the following pages.

IU Conversion Systems, Inc.--

IUCS markets a system of FGD sludge stabilization using lime and fly ash. In the IUCS process, vacuum filtered sludge is mixed with fly ash and lime in a pug mill. Figure 2 shows a schematic diagram of the IUCS system. Dry fly ash is added in proportions varying from 50 to 100 percent of the dry sludge weight. Lime is added at a rate of 3 to 4 percent. IUCS calls the finished material Poz-O-Tec®.

Disposal of the stabilized sludge is accomplished by landfilling. The mixture is controlled to optimize compaction properties. Pozzolanic reactions between the lime and fly ash result in a significant increase in load-bearing strength after the material has cured. Compared to untreated sludge, Poz-O-Tec has lower moisture content (15 to 25 percent), much reduced permeability (10^{-5} to 10^{-6} cm/sec) and compressibility, as well as increased bulk density. As an alternative to landfill disposal, Poz-O-Tec can be used as a structural or construction material. Possible uses include road base; pond, landfill, or reservoir lining; concrete or asphalt aggregate; and artificial reefs. IUCS has experimented with most of these applications, and can modify the stabilization process, as necessary, to produce an improved construction mixture.

Mechanical compaction of Poz-O-Tec is required to obtain the optimum strength and minimum permeability. If the compacted material is disturbed, it will undergo a decrease in density. Since the in-situ Poz-O-Tec material is unsaturated, disturbances will not reslurry the material.

The IUCS stabilization system can be applied to any type of calcium-based or calcium-regenerated dual-alkali sludge. Although Poz-O-Tec depends on dry fly ash as a pozzolan, wet fly ash can also be used; if no fly ash is available, other pozzolanic materials might be substituted at a higher cost. Although the IUCS process is not particularly sensitive to sludge chemical characteristics, such as sulfate/sulfite ratio or pH, physical characteristics, such as solids content, can be important parameters. At the IUCS Conesville, Ohio, facility, the untreated sludge is discharged from the scrubber loop, thickened (to about 35 percent solids), and then vacuum-filtered to 60 percent solids. After mixing, the Poz-O-Tec material can be stockpiled

TABLE 9. COMPANIES PROVIDING COMMERCIAL FIXATION OR DISPOSAL SERVICE

Companies	Commercial Experience with Other Residues	System Specific for FGD Sludge	Full-Scale Experience with FGD Sludge	Bench Scale with FGD Sludge	Field Tests with FGD Sludge
Aerojet Liquid Rocket	Extensive	Yes	None	Yes	None
Amax Resource Recovery Systems, Inc.	Extensive	Yes	None	Yes	None
*American Admixtures Company (Formerly Chicago Flyash)	No	Yes	Will County (140 Mw)	Yes	Will County
Anefco Company	Extensive	Yes	None	None	None
Chemfix	Extensive	Yes	None	Yes	Shawnee, Will County
Chem-Nuclear Systems, Inc.	Extensive	Yes	None	None	None
Dravo Corporation	Limited	Yes	Bruce Mansfield (1650 Mw)	Extensive	Shawnee, Mohave, Phillips
Environmental Technology Corp.	Limited	Yes	None	Yes	None
IUCS	Extensive	Yes	Phillips (400 Mw) Elrama (500 Mw) Petersburg (515 Mw) Conesville (403 Mw)	Extensive	Shawnee, Phillips, Mohave, Elrama, Four Corners
Marston Associates	No	Yes	None	Yes	St. Clair
Ontario Liquid Waste Disposal Limited	Extensive	Yes	None	Yes	Mississauga

TABLE 9 (continued)

Companies	Commercial Experience with Other Residues	System Specific for FGD Sludge	Full-Scale Experience with FGD Sludge	Bench Scale with FGD Sludge	Field Tests with FGD Sludge
TJK, Inc.	Extensive	Yes	None	None	None
Sludge Fixation Technology, Inc.	None	Yes	None	Yes	None
United Nuclear Industries	Extensive	Yes	None	Yes	None
Wehran Engineering Corporation	Not Known	Yes	None	Yes	None
Werner Pfleiderer Corporation	Extensive	Yes	None	None	None

* This company provides disposal services and operates fixation facilities at Commonwealth Edison's Will County Plant.

† Ref. 3.

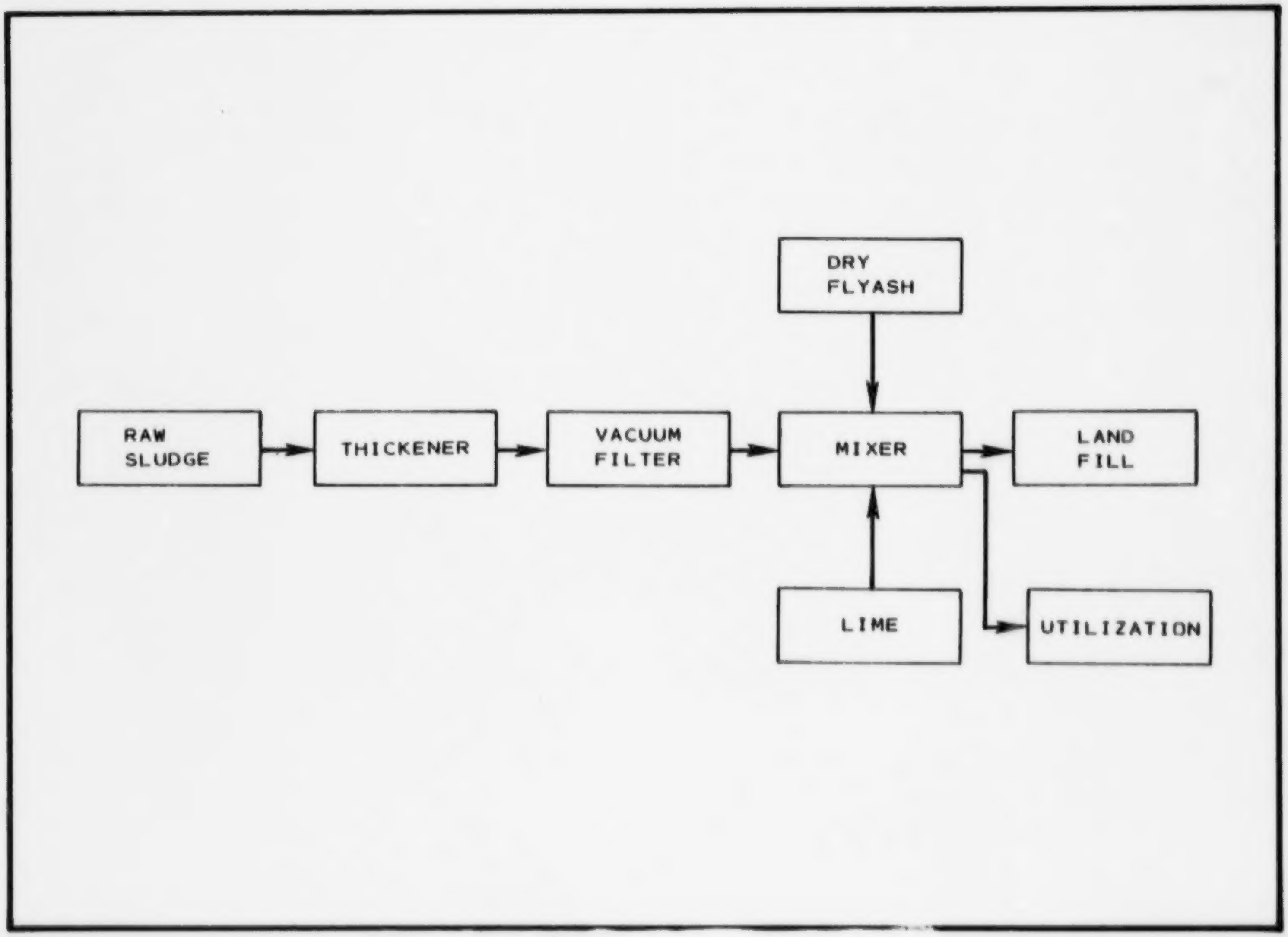
RAW
SLUDGE
THICKENER
VACUUM
FILTER
DRY
FLYASH
MIXER
LIME
LAND
FILL
UTILIZATION

Figure 2. Description of IU Conversion Systems' Poz-O-Tec process for FGD sludge stabilization.

↑
Systems'

without adversely affecting the curing process. Temperatures below 40°F will temporarily stop the stabilizing reactions, which will again resume as the ambient temperature increases.

Dravo Corporation--

The Dravo stabilization process (patented) involves the addition of Calcilox, a proprietary material manufactured from blast furnace slag, to the sludge. Calcilox is a basic, pozzolanic additive which improves sludge handling characteristics and disposal properties.

Three treatment/disposal schemes are possible using Calcilox as a stabilizing agent: permanent ponding, temporary ponding, and direct landfilling. These variations are shown schematically in Figure 3.

Permanent ponding (the variation employed at the CAPCO Bruce Mansfield facility) involves the addition of Calcilox and hydrated lime to the sludge before pumping the mixture to a holding pond. The hydrated lime is required to adjust the pH above 10.5. Calcilox is added at the rate of 5 to 10 percent of sludge solids. Curing is completed in approximately 30 days. Supernatant is then returned to the FGD system.

Where large tracts of land are not available, temporary ponding may be preferable. After the 30-day curing period, the stabilized sludge is excavated from small holding ponds and trucked to the landfill. More exact control must be exercised in order to ensure that the sludge cures properly before excavation.

In cases where a temporary storage site is not available, direct landfilling can be accomplished immediately following the addition of dry fly ash, lime, and Calcilox to filtered sludge solids. Sludge treated in this manner can be efficiently transported to the landfill location, where only 5 to 6 days' curing is needed before spreading.

The only full-scale operational FGD facility utilizing the Dravo stabilization system is the CAPCO Bruce Mansfield Station in western Pennsylvania, which employs permanent sludge ponding and supernatant recycle or discharge. This system has been in operation since December 1975, and was rated as one of the ten most outstanding engineering achievements of 1976 by the National Society of Professional Engineers. The treated slurry is pumped 7 miles to a storage reservoir. A similar system is being planned for a West Virginia utility. An interim ponding system was also demonstrated by Dravo at another Pennsylvania utility from 1974 to 1976, treating the sludge from 100 MW of FGD-controlled generating capacity.

Status of FGD Sludge Disposal

Figure 4 displays the cumulative U.S. power generating capacity served by each of the above-mentioned FGD sludge disposal

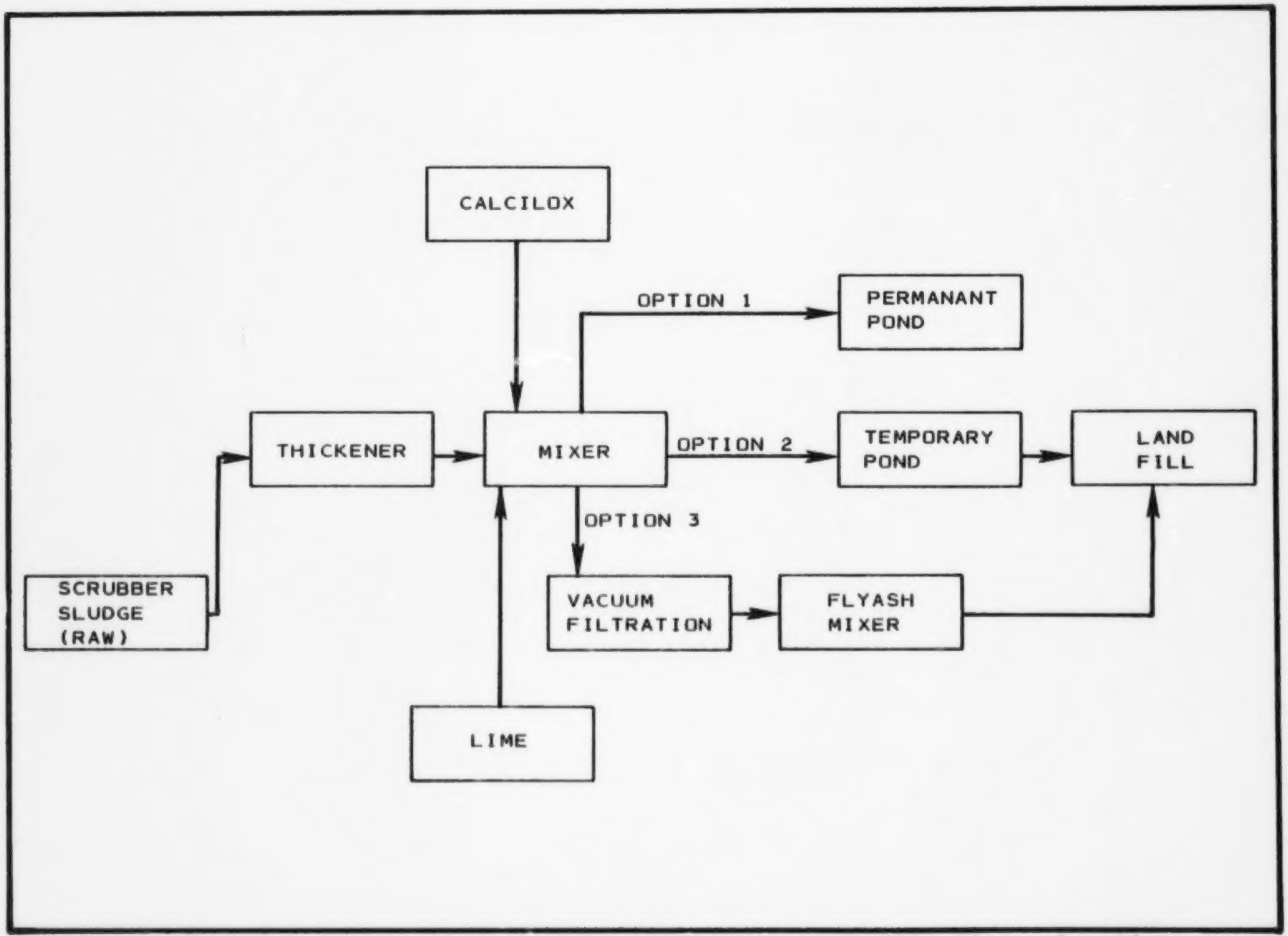
CALCILOX
OPTION 1
PERMANANT POND
THICKENER
MIXER
OPTION 2
TEMPORARY POND
LAND FILL
OPTION 3
SCRUBBER SLUDGE (RAW)
VACUUM FILTRATION
FLYASH MIXER
LIME

Figure 3. Dravo process flow diagram showing three possible disposal options.
3

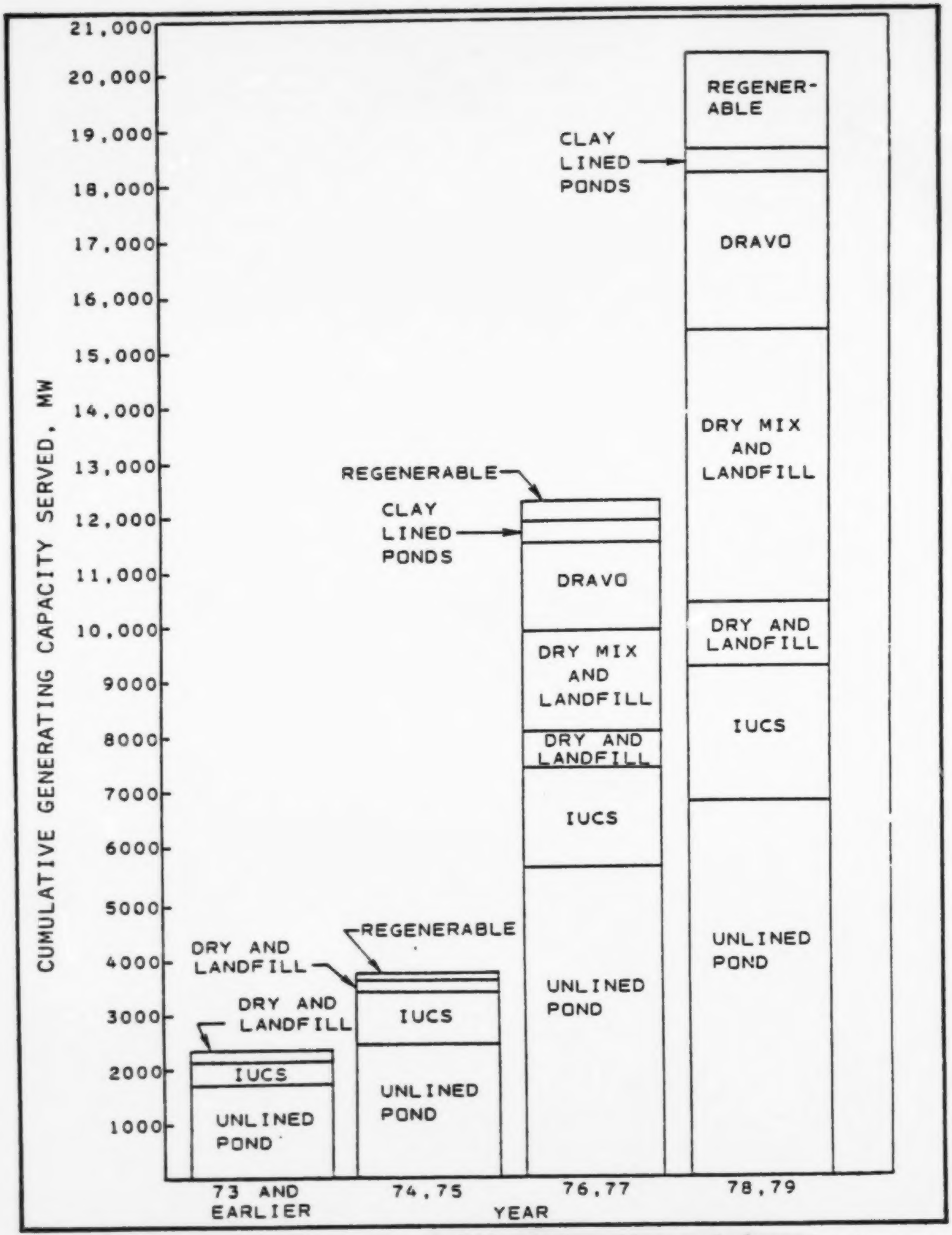

Figure 4. Status of wet FGD sludge disposal (see text for technology description).

34

technologies. Note that through 1979, each of these technologies has found steadily increasing application. It is also evident from the graph that dry disposal (dry, mix, and landfill; dry and landfill; and IUCS) is accounting for an increasing portion of the FGD sludge disposal capacity.

Figure 5 displays the same information, only in terms of cumulative disposal capacity by disposal practice. The graphs show that most of the dry disposal technologies are experiencing an increasing rate of growth in the industry, as are all forms of stabilization. Ponding, as a means of FGD sludge disposal, on the other hand, shows a declining rate of growth in the near term. These trends are expected to continue as the implementation of FGD continues to increase.

The trend toward stabilization and dry disposal is due in part to increased acceptance by some state regulatory agencies. While no state regulations requiring dry disposal have been promulgated to date, such a philosophy could have a distinct impact on the future of FGD sludge disposal.

In order to quantify the cost impact of several regulatory scenarios, such as the one mentioned above, a definitive set of disposal systems was developed. These are described in Table 10. Detailed cost estimates for each system are presented in Section 7 of this report.

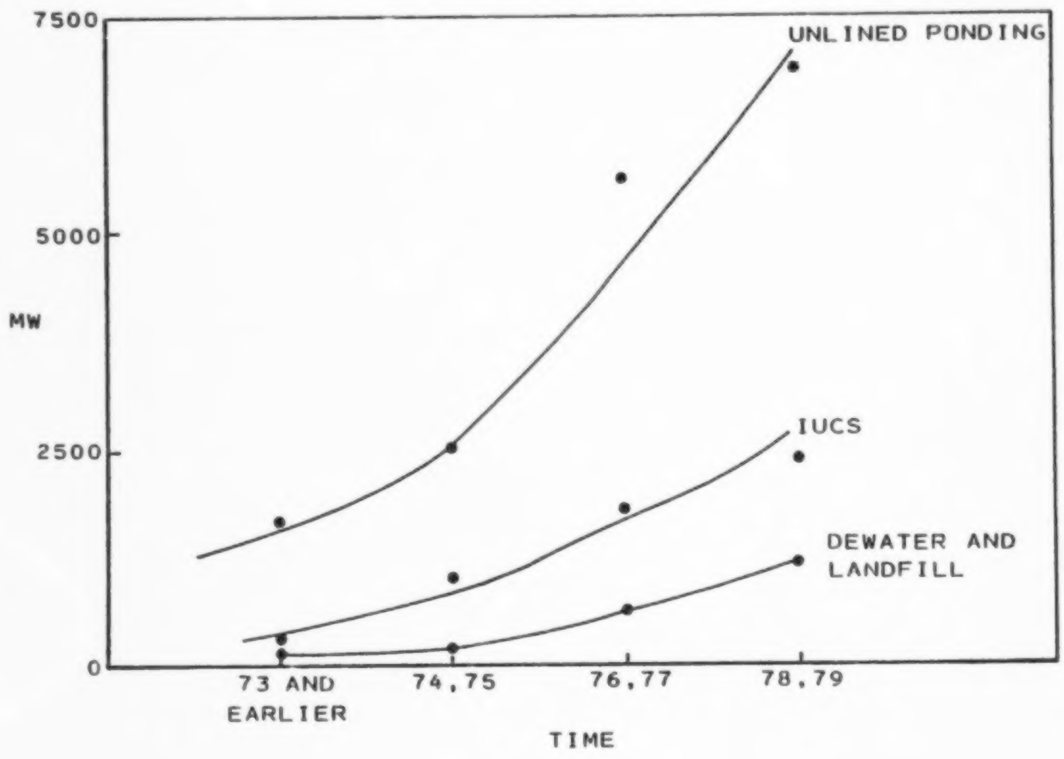

Figure 5. Trends in predominance of FGD sludge disposal practices among utilities.

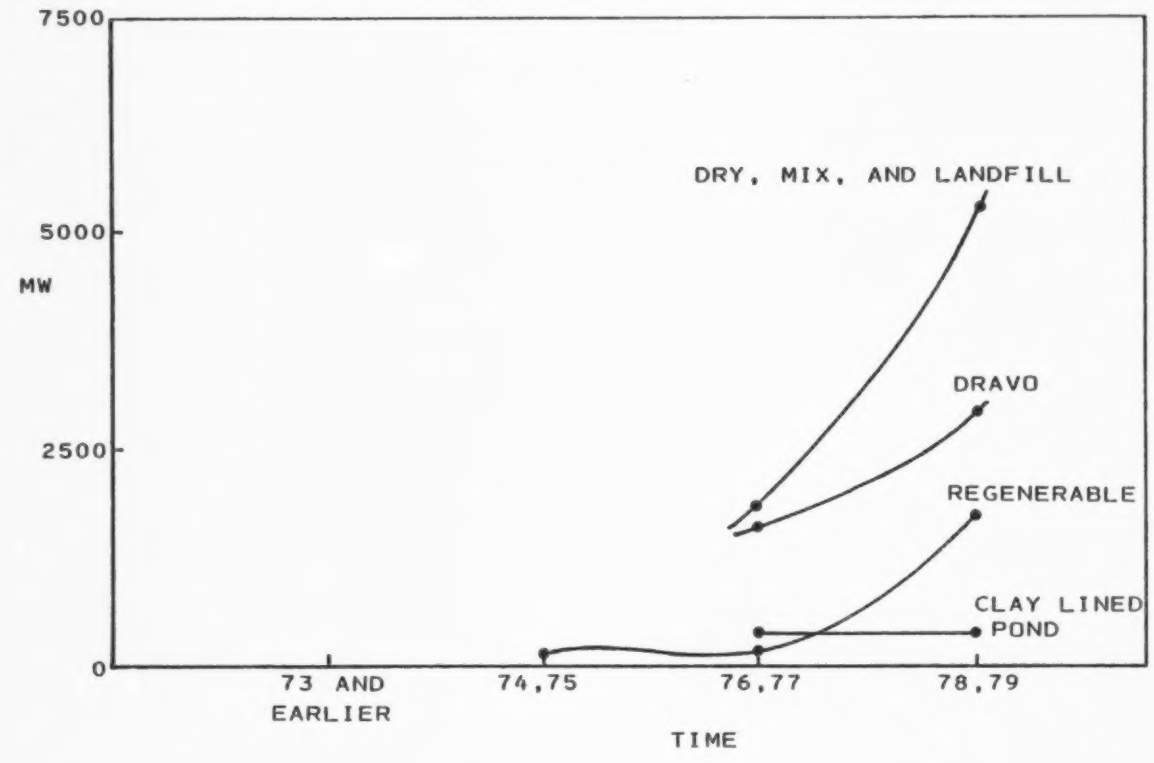

Figure 5 (Continued)

TABLE 10

TABLE 10. ALTERNATIVE DISPOSAL PRACTICES AVAILABLE FOR UTILITY-GENERATED FGD SLUDGE*

Disposal Practice	Flue Gas Cleaning		Sludge Attributes	Site Attributes†
	Particulate	SO_2		
Unlined pond	Scrubber	Limestone	35% Solids in effluent slurry, 50% solids settled	Pond, with acceptable in-situ soil liner
Clay-lined pond	Scrubber	Limestone	35% Solids in effluent slurry, 50% solids settled	Pond, with imported clay liner
Dewater and landfill	Scrubber	Limestone	Clarified to 35% solids, filtered to 60%	Landfill, with necessary distribution and compaction equipment
Dravo treatment	Scrubber	Limestone	Treated slurry pumped to pond or impoundment	Pond impoundment with acceptable in-situ liner
I.U.C.S. treatment	ESP	Limestone	Clarify to 35% solids, filtered to 60%, add fly ash	Landfill or backfill with equipment
Dewater, lime, fly ash admix	ESP	Limestone	Clarify to 35% solids, filtered to 60%, add fly ash	Landfill or backfill with equipment

*Other alternatives, such as synthetic liners, chemfix treatment, Dravo treatment (solids only), were not considered due to lack of application through 1980.

† Reference to liners is by necessity simplistic, due to the broad range of site-specific physical constraints the liner must meet.

SECTION 6

THE REGULATION OF FGD SLUDGE

GENERAL

The major federal laws possibly affecting disposal of FGD sludge fall into several categories:

- Solid waste disposal (including hazardous waste disposal).
- Air quality criteria.
- Water discharge regulations.
- Ocean dumping.
- Mine disposal.
- Safety and health regulations.
- Water quality criteria for beneficial use.

Design of FGD disposal systems may require compliance with provisions of the regulations listed above.

The major federal statutes impacting FGD sludge disposal are summarized in the following sections. The majority of these regulations are less than 2 years old; thus, they have not been applied extensively. It is expected that court rulings will more precisely define the applicability of these laws to the problem of FGD sludge disposal.

CLEAN AIR ACT AND AMENDMENTS

The goal of the CAA and its amendments is the attainment of national ambient air quality criteria. An important link in the strategy for reducing emissions to acceptable levels is the NSPS. NSPS for fossil fuel-fired steam generators (40 CFR, Part 466, 8-17-71) resulted in the designation of lime/ limestone wet scrubbers as the most practicable flue gas SO_2 control method. Difficulties were encountered, however, with procedures for disposing of the large volumes of sludge expected to be generated. This culminated in a Court of Appeals judgement remanding the question of FGD sudge disposal to EPA for further consideration. At the time the SO_2 emission standard for fossil fuel-fired steam generators was under review by EPA, Congress passed the 1977 CAA amendments. These amendments replaced the previous fixed emission limitation for SO_2 with one based on a percent reduction from an uncontrolled system. The new emission standard is considered more stringent, and is expected to result in greater FGD sludge production.

Since most vehicles and machinery used in FGD sludge disposal (i.e., sludge transportation by tank truck, use of excavation equipment at the disposal site, etc.) could result in additional air pollutant emissions, compliance with CAA-mandated and EPA-approved implementation plans may need to be assured before a sludge disposal system can be initiated. Emission quantities would normally be analyzed and compliance verified during the normal environmental review process. The increase in air pollutant loading, due to currently proposed FGD disposal activities, would not normally be a major obstacle to compliance.

FEDERAL WATER POLLUTION CONTROL ACT (PL 92-500)

FGD sludges come under federal water quality guidelines if they are discharged to an interstate body of water. Discharges from FGD facilities can include untreated sludge, treated sludge, or sludge liquor. No specific effluent limitations have been promulgated for FGD sludges to date; however, discharged industrial wastewater streams of any kind must be subjected to the "best practical" treatment technology. By July 1, 1983, they must be subjected to the "best available" treatment technology. Any discharge to navigable water is allowed only under the conditions of the National Pollutant Discharge Elimination System (NPDES). It is the intent of PL 92-500 that NPDES act as an interim policy, as a step towards the elimination of all discharges to navigable waters by 1985.

An NPDES permit regulates parameters such as point of discharge, flow rate, time of discharge, effluent limitations, compliance and monitoring schedule, and operation and maintenance requirements. EPA enforces NPDES permit violations directly, unless authority has been delegated to an approved state agency.

Standards for NPDES permits are such that ultimate disposal of any FGD wastes (treated or untreated) into navigable waters could only be allowed on an intermittent, low-volume basis, if at all.

RESOURCE CONSERVATION AND RECOVERY ACT OF 1976 (PL 94-580)

The RCRA of 1976 (PL 94-580) considerably altered the federal role in the regulation, treatment, and disposal of solid wastes. Prior to PL 94-580, federal activity in solid waste regulation was advisory; state and local officials maintained jurisdiction. The Solid Waste Disposal Act of 1965 and the Resource Recovery Act of 1970 espoused this philosophy, providing only for technical assistance and guidance in promulgating standards. In accordance with PL 94-580, federal solid waste management activities became centralized within EPA under the Office of Solid Waste (OSW), directed by a deputy assistant administrator. Consideration is given to maintaining coordination between state and local agencies, as stated in Objective, Subtitle D, of the act: "Such objectives (environmentally sound disposal of solid waste) are to be accomplished through federal, technical, and financial assistance to state or regional authorities for comprehensive planning pursuant to federal guidelines designed to foster cooperation among federal, state, and local governments and private industry." PL 94-580 and its predecessors contain several provisions which influence FGD sludge disposal.

The applicability of PL 94-580 to land disposal of FGD sludge is set forth in the guidelines (Section 1008(a)), i.e., protection of the public health and welfare through: (1) protection of the quality of ground waters and surface waters from leachates; (2) protection of the quality of surface waters from runoff; (3) safety; and (4) aesthetics. The implementation of these guidelines is dependent on whether FGD sludges are ultimately defined under PL 94-580 as general hazardous wastes.

At present, PL 94-580 defines sludge from air pollution control facilities as solid waste (Section 1004(27)). Under Section 1004(5), however, hazardous waste is defined as a waste which can cause or significantly contribute to an increase in mortality or serious illness, or one which poses a substantial present or potential hazard to human health or to the environment. EPA has issued a list of materials to be categorized as hazardous under RCRA (Subtitle C). FGD sludge was not included initially, but was instead categorized as a "special waste," to be classified as hazardous or nonhazardous on an individual basis.

The criteria for identifying hazardous wastes may include: ignitability, corrosivity, infectiousness, reactiveness, radioactiveness, and toxicity. Wastes not on the EPA list, but meeting these criteria, will also be subject to EPA regulations.

A two-phase process being considered in the identification of hazardous wastes includes: (1) criteria for identifying the characteristics of the hazardous substances; and (2) the development of a list of specific hazardous wastes and a presumptive industrial process list. The latter list specifies industrial processes which will be assumed to be producers of hazardous wastes, unless the affected industrial facility proves otherwise. Industrial processes producing SO_2 scrubber sludge and ash handling systems are among those being considered for this list.

Identification of FGD sludges as hazardous under Subtitle C, Hazardous Waste Management, would necessitate a permit system as well as strict regulations regarding the recording, labeling, storage, treatment, transport, and disposal of such materials. enforcement of hazardous waste regulations would be delegated to individual states, if they desire, through the establishment of a state hazardous waste program.

Nonhazardous wastes are regulated only in that proper sanitary landfill techniques must be employed. EPA-recommended guidelines for proper design and operation of landfills have been published (FR 39 (158):29327-37). Particular reference is made to procedures designed to prevent ground water contamination and flooding, and to enhance site reclamation. Factors influencing water quality include:

- Background water quality.
- Water table elevation and movement.
- Site geology and soil characteristics.
- Meteorology (particularly precipitation).

Measures which should be undertaken to prevent possible degradation include:

- Installation and monitoring of ground water wells.
- Leachate, well, and other water testing.

In some instances, EPA recommends installation of leachate collection systems. To prevent inundation during periods of flooding, they recommend impervious dikes or other means to protect against at least a 50-year design flood. To enhance the aesthetics of a landfill area, replacement of vegetative cover, as soon as possible, is advised. These guidelines are only enforceable by the states, and the states are not required to subscribe to them.

The possibilities for federal regulations of FGD sludge are shown in Figure 6. Only the level of control depicted in the upper branch of the figure would then apply.

If FGD sludge is categorized as a hazardous waste, federal regulations will control every phase of treatment and disposal.

THE MARINE PROTECTION, RESEARCH, AND SANCTUARIES ACT OF 1972 (PL 92-532)

Disposal of waste material (including FGD sludge) to the oceans is controlled by the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532). This act centralizes control of all ocean disposal under the EPA. Under this law, a permit system was established (38 FR 28613). Certain materials, such as radioactive wastes, chemical and biological warfare agents, and other infectious or particularly hazardous wastes, are specifically excluded from any or all ocean dumping. In general, disposal materials must not "unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."

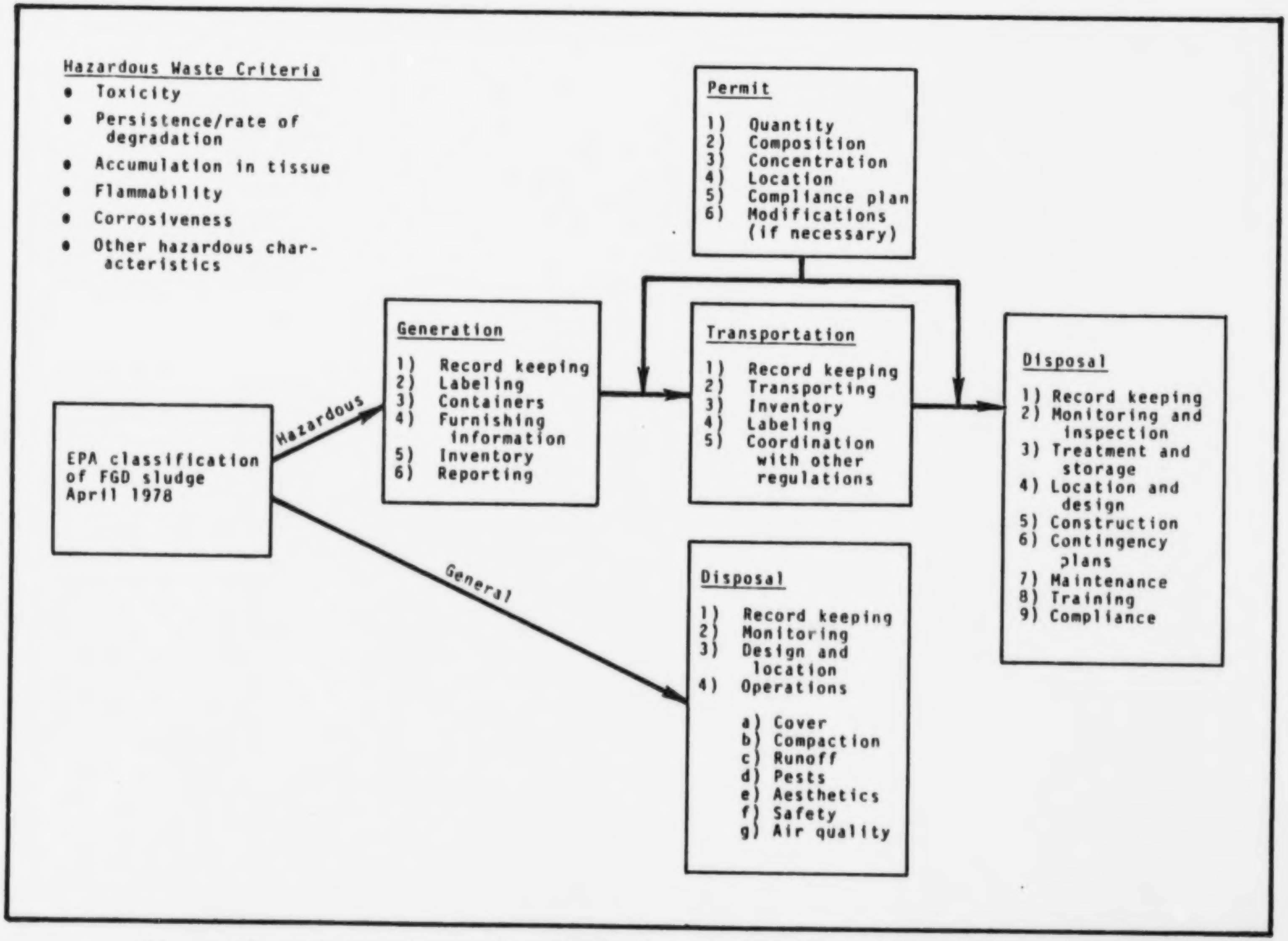
Hazardous Waste Criteria
• Toxicity
• Persistence/rate of degradation
• Accumulation in tissue
• Flammability
• Corrosiveness
• Other hazardous characteristics
EPA classification of FGD sludge April 1978
Hazardous
General
Generation
1) Record keeping
2) Labeling
3) Containers
4) Furnishing information
5) Inventory
6) Reporting
Permit
1) Quantity
2) Composition
3) Concentration
4) Location
5) Compliance plan
6) Modifications (if necessary)
Transportation
1) Record keeping
2) Transporting
3) Inventory
4) Labeling
5) Coordination with other regulations
Disposal
1) Record keeping
2) Monitoring and inspection
3) Treatment and storage
4) Location and design
5) Construction
6) Contingency plans
7) Maintenance
8) Training
9) Compliance
Disposal
1) Record keeping
2) Monitoring
3) Design and location
4) Operations
a) Cover
b) Compaction
c) Runoff
d) Pests
e) Aesthetics
f) Safety
g) Air quality

Figure 6. Alternatives for federal regulation of FGD sludge disposal under the Resource Conservation and Recovery Act.

Applicants for ocean disposal permits must inform the EPA of the following:

- Quantity of material to be dumped.
- Means of conveyance.
- Anticipated dates and times of disposal.
- Proposed dump site.
- Proposed method of disposal.
- Identification of the process producing the waste.
- Alternative methods of disposal and reasons why they cannot be used.

In addition, wastes containing any of the following substances fall into the "special care" category, and the permit applicant is required to prove that "the material proposed for disposal, after reasonable allowance for mixing in the mixing zone, will not exceed .01 of a concentration shown to be toxic to appropriate sensitive marine organisms, considering the concentration of pollutants, in the waste material itself and the total mixing zone available for initial dilution and dispersion." These substances are: elements, ions and compounds of arsenic, lead, copper, zinc, selenium, vanadium, beryllium, chromium, and nickel. Also included are organosilicon compounds, inorganic processing wastes, petrochemicals, biocides, radioactive wastes not otherwise prohibited, wastes high in BOD, immiscible materials and substances included on the EPA's toxic pollutants list. Applicants for ocean disposal permits must determine that no applicable water quality standards will be violated by their disposal. They must also consult with federal, state, and local authorities and take affirmative action to inform the general public about the proposed dumping.

Federal ocean dumping regulations and permit procedures are designed to discourage ocean disposal wherever possible. Proposed dumping activities will be approved only after the applicant has established: need; economic, aesthetic, recreational, and marine ecosystem effects; long-term effects; and has considered alternative land-based disposal and reuse potential. FGD sludge disposal research is continuing in this area.

DISPOSAL TO MINES

Disposal of FGD sludge to mines will be regulated under the Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87). Starting in January 1979, the act will establish criteria on the types of materials to be stored and disposed of in both surface and deep mines, during and following mining operations.

FGD sludge disposal in coal mines is considered acceptable under the current law (PL 95-87). Several provisions, however, will govern storage: (1) the ability to ultimately reclaim the surface land; (2) pollution problems caused by stored materials; and (3) effect of the stored materials on the hydrogeology of the site. In addition, individual states will be required to inspect all coal mines to ensure their compliance with relevant federal statutes.

The act will be administered by the Department of Interior, Office of Surface Mining Regulations. They will coordinate their efforts with EPA, which enforces the RCRA, PL 94-580. The regulations regarding leachate control, ground water and surface water protection, safety, and aesthetics are all equally applicable to mine disposal.

As discussed in the section describing RCRA, the degree of federal regulation of FGD sludges will hinge on whether they are defined as hazardous wastes. With the enactment of the Hazardous Waste Management Guidelines (Subtitle C of RCRA), EPA will be involved in the regulation of hazardous wastes from the point of generation to the point of disposal.

Mine disposal of FGD sludge will be partially regulated by several federal water quality laws, notably the Federal Water Pollution Control Act amendments and the Safe Drinking Water Act. Although effluent guidelines have not, as yet, been promulgated for FGD sludges, point-source effluent limitations for mines have been completed and are being reviewed. Additional effluent limitations regulate discharges to surface waters used for public water supplies. Surface runoff, the pumping of ground water from mines, and seepage or overflow of sludge liquor are all examples of potential FGD mine disposal discharges which would be regulated by the above laws.

The Safe Water Drinking Act (PL 93-523) pertains to mine disposal of FGD sludge with regard to potential contamination of aquifers used as sources for drinking water. The EPA administrator has broad powers to regulate disposal activities in an emergency situation, or to block federal funding of disposal projects if potential contamination of aquifers is likely.

Several federal safety regulations can be applied to mine disposal of FGD sludge and ash. In particular, the Dam Safety Act, PL 92-367, could be applied in cases where dikes are constructed to contain waste material. Structures covered by this law must have impoundment capability greater than 14 acre-feet, or have a height greater than 6 feet.

Certain Mining Safety and Health Administration (MSHA), as well as Occupational Safety and Health Administration (OSHA), standards and guidelines indirectly bear upon FGD sludge disposal activities. Customarily, OSHA monitors the disposal industry, and MSHA, the mining industry. Their separate jurisdictions with regard to disposal in mines, however, are not specified in the standards and guidelines and, therefore, jurisdictions tend to overlap. Overall, MSHA and OSHA regulations are directed towards the working environment of employees, rather than towards environmental protection in general. Examples of regulations which could be applied to FGD waste disposal are: materials storing guidelines, hazardous materials container and storage standards, or impounding structure specifications.

STATE FGD DISPOSAL REGULATIONS

State solid waste regulations are generally directed towards protection of ground water, site reclamation, and potential flooding. Many states also evaluate criteria on a site-specific basis, requiring power plants utilizing FGD to obtain disposal site approval from the applicable state agency. None of the states surveyed had developed specific FGD sludge disposal criteria. Permit applications were evaluated based on adapted landfill regulations which, in many cases, were limited to a soils analysis. Table 11 summarizes disposal regulations for states in which an FGD facility was located in 1977.

An FGD sludge disposal system which produces a discharge to surface waters (such as with treated liquor) is subject to the requirements of the water quality standards program. Every state operates such a program to monitor and restrict pollutant discharges. Constituents and parameters such as DO, pH, SS, and heavy metals are regulated. FGD sludge contains all of these as constituents.

Most states also limit the pollutant loading of ground water systems. Specific criteria for such protection, however, is not as well developed as it is for surface waters. Kansas, Maryland, Michigan, New York, and Idaho have established contaminant limits which require ground water discharge permits or regulate disposal practices; however, the majority of states do not, as yet, have quantitative guidelines affecting pollutant discharge to ground water aquifers.

REGULATORY SCENARIOS DISCUSSIONS

Four alternative regulatory scenarios for the disposal of flue gas cleaning sludge are conceivable, as listed below:

- Federal Advisory - State Legislation and Enforcement.
- General Federal Legislation - State Enforcement.
- Comprehensive Federal Legislation - State Enforcement upon Approval.
- Comprehensive Federal Legislation and Enforcement - No State Involvement.

Each scenario is dependent upon the authority assumed by the federal and state/local governments. The greater the role of the federal government in the regulation of FGD sludge, the greater the national uniformity in treatment, transport, and disposal

TABLE 11. STATE SOLID WASTE REGULATIONS PERTAINING TO SELECTED FGD SYSTEMS*

State	Groundwater	Floods	Rainfall	Reclamation
AZ	General protection	None	None	2 ft minimum cover
CO	General protection	General rainfall protection	General rainfall protection	
FL	Monitoring, possible leachate collection	Away from flood plain	General diversion	2 ft minimum cover, 33% slope (sides)
IL	Monitoring, soil analysis	General rainfall protection	General rainfall protection	2 ft minimum cover, 50% slope (sides)
KS	General protection, soil analysis	None	None	State approval
KY	General protection, soil analysis	100 yr flood	General diversion	2 ft minimum cover, revegetation
MO	Monitoring, soil analysis, possible leachate collection	100 yr flood	20 yr rainfall	2 ft minimum cover, 33% slope (sides) revegetation
MT	General protection, soil analysis	100 yr flood	20 yr rainfall	2 ft minimum cover,
NV	Stabilize or neutralize	None	None	2 ft minimum cover, 2-4 slope
PA	Monitoring, soil analysis, possible leachate collection	50 yr away from flood plain	General diversion	2 ft minimum cover, 1-15% slope

* Ref. 25.

standards. Comprehensive federal regulations would most likely ensure uniform enforcement also.

On the other hand, the greater the role of the state government in FGD sludge disposal regulations, the greater the chances that particular needs of a disposal facility and the surrounding community will be recognized. Site-specific regulations would allow the state or local regions to evaluate individual disposal facilities. Unique situations and locations would be recognized. Table 12 summarizes the four alternative administrative approaches to FGD sludge disposal regulations.

Each of the four regulatory approaches listed above may result in different compliance procedures. Based on a prior study (25) of the development of standards/regulations for land disposal of FGD sludge, the following general categories of procedures were defined:

1. Simple permitting; stabilization not required and not commonly used.

2. Site-specific evaluation with stabilization sometimes required.

3. Physical stabilization required; no ponding.

4. Chemical stabilization required in urban areas.

5. Chemical stabilization universally required; specifications given for the stabilization technique.

Each of these five compliance requirements are further described in Table 13 as they relate to the four administrative alternatives. In Section 7, these regulation compliance scenarios are applied to the projected 1980 and 1985 FGD sludge disposal capacity to determine their impact on present and future disposal operations.

TABLE 12. ALTERNATE REGULATORY SCENARIOS FOR FLUE GAS CLEANING SLUDGE DISPOSAL

Scenario	Federal Role	State/Local Role	General Description
One	Advisory	Legislative and Enforcement	Federal government delegates regulatory authority to states. Type of regulation and enforcement procedures will be site specific; therefore,no national uniformity.
Two	Legislative (General)	Enforcement	Federal government promulgates regulatory legislation and/or general pollution abatement legislation. Enforcement of federal legislation is delegated to the individual states. Each state would set their individual compliance procedures for site design, selection, operation, etc.
Three	Legislative (Comprehensive)	Enforcement	Federal government promulgates specific and comprehensive regulatory legislation. Federal legislation would include specific guidelines for the site design, selection, operation, monitoring, and reclamation. States, upon certification by federal authority, would be responsible for enforcement of federal legislation.
Four	Legislative and Enforcement	None	Federal government is responsible for legislation and enforcement. State has no rule (besides cooperation with federal authorities). Federal role could range from "cradle to grave" control of FGD to periodic permit programs. Federal enforcement would encourage national uniformity but may slight unique conditions of state and local facilities.

TABLE 13. MANIFESTATION OF REGULATORY SCENARIOS*

Compliance Scenario	Responsibility		Possible Requirements			
	Federal	State	Groundwater	Land	Surface Water	Site Design
1,2	Advisory	Legislative and Enforcement	• General protection	• None; or • Stability (site specific)	• NPDES	• Approved engineering criteria
3	Legislative (general)	Enforcement	• Specific protection (monitoring)	• Stability	• NPDES	• Specified engineering criteria
4	Legislative (comprehensive)	Enforcement	• Quantify expected contamination • Remedial plans • Monitoring	• Meet or exceed surrounding stability	• NPDES or treatment	• Specified engineering criteria
5	Legislative and enforcement	None	• De facto protection	• Chemical Fixation	• No discharge; dike construction standards	• Specified engineering criteria

---

* Interpreting 1 to 4 as increasing stringency.

SECTION 7

DEVELOPMENT OF MODEL POWER PLANTS AND ASSOCIATED FGD SLUDGE DISPOSAL COSTS

INTRODUCTION

The objective of this study is to estimate the cost impact of various degrees of FGD sludge disposal regulation on the utility industry. In order to make such an estimate, the following information is required:

- One or more alternative regulatory approaches for FGD sludge disposal, and the designation of disposal methods which can meet or exceed the associated criteria.
- A set of model power plants which together represent the utility industry.
- The cost of each disposal option to each model plant.

The cost impact assessment can then be made by (1) applying each regulatory scenario to the model plants (industry profile), (2) estimating the disposal method used by each plant for compliance, and (3) estimating the incremental industry-wide cost of compliance beyond that of current regulations. The technology options and regulatory scenarios were presented in Sections 5 and 6, respectively. This section presents the model plant and cost data development. Section 8 combines this information for the cost impact assessment.

MODEL PLANT ATTRIBUTES

Although considerable sludge disposal cost information exists, much of it is based on differing design and economic premises. Because it is important that a consistent methodology be followed in developing all disposal cost estimates, the recent TVA conceptual design study (4) of sludge disposal economics has been selected as a basis for the formation of the model plants.

The base case model in the TVA study described a new 500-MW coal-fired plant near Chicago, with construction costs for mid-1979 and first-year operation costs for mid-1980. The coal composition varied from 2 percent to 5 percent for sulfur, and from 12 percent to 16 percent for ash.

In developing model plants for this report, the industry was differentiated based on the type of coal most typically used. Because of high transportation costs and the dissimilarity of coals mined in various parts of the country, the first step in developing model plants was to divide the industry by geographic region. Although this approach is a simplification, some generalization is necessary to keep the number of model plants reasonable.

Table 14 presents the selected model plants with their appropriate fuel composition counterparts. Where possible, actual industry data were used to characterize fuel types for each region.

TABLE 14. MODEL PLANT LOCATION AND FUEL CHARACTERISTICS

Region	Name	Coal Composition % Sulfur	 % Ash
West	Western	2	12
Midwest	Midwest 1	3.5	12
	Midwest 2	5	16
East	Eastern 1	2	12
	Eastern 2	3.5	16

Table 15 lists the states within the regions selected and the Standard Metropolitan Satistical Areas (SMSA), which presumably typify the larger metropolitan areas of each region. The SMSA's are identified to allow inclusion of urban-rural variations in land prices in the model plant descriptions. Variability of land prices within each region is introduced by constructing each model plant under two land cost criteria: (1) construct it within a "typical" SMSA of that region, and (2) construct it in a non-SMSA county which closely adjoins that SMSA.

However, because the task of selecting a "typical" SMSA is difficult, Table 16 presents a more simplified methodology for typifying urban and rural land prices within each region. In this table, statewide agricultural land prices for states containing the representative SMSA's were collected from Department of Agriculture sources and projected to mid-1979. This mid-1979 projection is compatible with the method that TVA used for projecting capital costs. Since the most current prices on a county basis are for 1974, statewide 1974-1979 growth factors were applied to counties within and adjoining the representative SMSA's. The simple averages of these estimated land values are used in

TABLE 15. MODEL PLANT REGIONAL CHARACTERISTICS

Region	Representative S.M.S.A.'s	Member States	
West:	Albuquerque	Arizona	New Mexico
	Denver-Boulder	Colorado	Utah
	Las Vegas	Idaho	Wyoming
	Phoenix	Montana	
	Salt Lake City	Nevada	
	Tucson		
Midwest:	Chicago	Arkansas	Missouri
	Cleveland	Illinois	Nebraska
	Dallas-Ft. Worth	Indiana	North Dakota
	Detroit	Iowa	Ohio
	Houston	Kansas	Oklahoma
	Minneapolis	Louisiana	South Dakota
	St. Louis	Michigan	Texas
		Minnesota	Wisconsin
East:	Baltimore	Alabama	New Jersey
	Boston	Connecticut	New York
	Nassau-Suffolk	Delaware	North Carolina
	New York	Florida	Pennsylvania
	Philadelphia	Georgia	Rhode Island
	Pittsburgh	Kentucky	South Carolina
	Washington, D.C.	Maine	Tennessee
		Maryland	Vermont
		Massachusetts	Virginia
		Mississippi	Washington, D.C.
		New Hampshire	West Virginia

16

TABLE 16. REGIONAL LAND PRICES*

		Statewide Land Prices						Within SMSA			Adjoining SMSA		
Region	Representative SMSAs	State	'69 Avg.	'74 Avg.	'77 Avg.	'79 Est.†	'74-'79 Factor#	Representative County	'74 Avg.	'79 Est.**	Representative County	'74 Avg.	'79 Est.**
West	Albuquerque	NM	43	71	95	106	1,493	Bernadillo	381	569	Torrance	53	79
	Denver-Boulder	CO	93	186	262	299	1,608	Boulder	779	1,252	Morgan	276	444
	Las Vegas	NV	54	85	94	107	1,259	Clark	433	545	Nye	76	96
	Phoenix	AZ	110	111	129	129	1,162	Maricopa	700	814	Yavapai	64	74
	Salt Lake City	UT	90	193	246	287	1,487	Salt Lake	618	919	Summit	209	311
	Tucson	AZ	110	111	129	129	1,162	Pima	121	141	Cochise	108	126
Ratio SMSA to Non-SMSA Averages is 3.76:1								Simple Average:		707	Simple Average:		188
Midwest	Chicago	IL	490	849	1,450	1,582	1,863	Cook	2,442	4,550	Boone	929	1,731
	Cleveland	OH	406	717	1,131	1,248	1,741	Cuyahoga	3,448	6,002	Wayne	764	1,130
	Dallas-Ft. Worth	TX	140	277	298	355	1,282	Dallas	1,357	1,739	Jack	183	235
	Detroit	MI	328	552	782	869	1,574	Wayne	1,920	3,023	Sanilac	520	819
	Houston	TX	140	277	298	355	1,282	Harris	890	1,141	Polk	418	536
	Minneapolis	MN	229	434	664	743	1,712	Hennepin	1,187	2,032	Stearns	318	544
	St. Louis	MS	240	398	529	591	1,485	St. Louis	1,118	1,660	Washington	267	396
Ratio SMSA to Non-SMSA Averages is 3.60:1								Simple Average:		2,878	Simple Average:		799
East	Baltimore	MD	634	1,037	1,371	1,527	1,473	Baltimore	1,590	2,341	Frederick	1,062	1,564
	Boston	MA	576	966	1,143	1,301	1,347	Middlesex	2,049	2,760	Worchester	786	1,059
	Nassau-Suffolk	NY	274	507	591	686	1,353	Suffolk	4,607	6,234	Dutchess	917	1,241
	New York	NY	274	507	591	686	1,353	Westchester	4,944	6,690	Dutchess	917	1,241
	Philadelphia	PA	391	756	1,000	1,145	1,515	Philadelphia	2,246	3,402	Berks	1,114	1,687
	Pittsburgh	PA	391	756	1,000	1,145	1,515	Allegheny	850	1,287	Greene	307	460
	Washington, D.C.	DC	634	1,037	1,371	1,527	1,473	Prince George	1,725	2,540	Frederick	1,062	1,564
Ratio SMSA to Non-SMSA Averages is 2.87:1								Simple Average:		3,608	Simple Average:		1,259

---

[*] All costs are $/acre for land from farms with $2,500 plus annual gross (i.e., very small farms are excluded). Except for '79 estimates, land prices are from agricultural census sources.

[†] This estimate comes from linear regression of statewide prices for '69, '74, and '77.

[#] This factor is the ratio of '79 estimate prices to '74 prices.

[**] This estimate is product of '74 average county price and '74-'79 statewide factor. The most recent prices for each county are for 1974.

the model plant descriptions as representative of the urban-rural range of land prices most likely to be encountered when siting a power plant within each region.

The TVA study estimated mid-1979 construction and mid-1980 operating costs for plants in the Chicago metropolitan area. To adjust these costs to other geographic regions, regional cost indices were used. Indices for 1979 and 1980 are not yet available, so it is assumed that relative differences between current indices may be used as close substitutes. Table 17 presents the Handy-Whitman electric utility construction indices for mid-1977 and the model plant regional construction cost indices for mid-1979.

TABLE 17. REGIONAL CONSTRUCTION COST INDICES*

	Handy-Whitman Index		Model Plant
Region	State Grouping	Index Number	Construction Cost Index†
West	Plateau	395	980
Midwest	N. Central	403	1,000
East	N. Atlantic	398	988

* Ref. 27.

† Methodology assumes same relative sizes of mid-1977 Handy-Whitman electric utility construction indices for mid-1979. North Central = 1,000.

A similar method was used to form operating and maintenance cost indices in Table 18. In this case, Department of Labor 1977 wage rates for each of the representative SMSA's were averaged and then compared to the Chicago base rate to form regional operating cost indices. As in the preceding table, these indices are relative to the cost estimates developed by TVA for the Chicago area. In this way, they allow model plant descriptions to incorporate regional cost differences for plant construction and operation.

Table 19 summarizes the model plant attributes. Even with the indicated simplifying assumptions, the methodology requires each of five model plants to be considered in both an urban (high-priced land) and a rural (low-priced land) setting.

TABLE 18. OPERATING AND MAINTENANCE REGIONAL COST INDICES

Region	Representative S.M.S.A.	Wage Rate*	Regional Index
West	Albuquerque	4.57	
	Denver-Boulder	5.79	
	Las Vegas	7.53	
	Phoenix	5.59	
	Salt Lake City	4.94	
	Tucson	5.63	
	Average	5.675	908
Midwest	Chicago	6.25	
	Cleveland	6.86	
	Dallas-Ft. Worth	5.06	
	Detroit	8.05	
	Houston	6.63	
	Minneapolis	6.44	
	St. Louis	6.59	
	Average	6.554	1,049
East	Baltimore	6.30	
	Boston	5.57	
	Nassau-Suffolk	5.21	
	New York	5.47	
	Philadelphia	5.64	
	Pittsburgh	7.23	
	Washington, D.C.	5.48	
	Average	5.843	935

* Source is Bureau of Labor Statistics, U.S. Department of Labor. Methodology assumes 1977 average wage rate differentials are good adjustments for 1980 Chicago O&M costs. Index is Chicago = 1,000.

TABLE 19. SUMMARY OF MODEL PLANT ATTRIBUTES

Base Case: 500 MW
30 Yr. Life (New)
1 Mi. to Disposal Site

	Land Costs/Acre		Construction	O&M		Coal Type	
Region	High	Low	Cost Index	Cost Index	Model Plant Name	% S	% Ash
West	707	188	980	908	Western	2	12
Midwest	2,878	799	1,000	1,049	Midwest 1	3½	12
					Midwest 2	5	16
East	3,608	1,259	988	935	Eastern 1	2	12
					Eastern 2	3½	16

UNIT COST DEVELOPMENT

Methods/Assumptions

Because model plant attributes differ from the base case presented by TVA, it is necessary to address the accounting methodology and assumptions used to generate unit cost estimates. As in the TVA report, annual revenue requirements for sludge disposal are divided into direct and indirect cost components. As Table 20 shows, the direct costs consist of those for delivered raw materials (e.g., ground lime) and for plant "conversion." This latter category includes: (1) operating labor and supervision, (2) maintenance (at 4 percent for plant and 3 percent for pond of direct investment), (3) analyses and operation (operation cost refers to landfill operation, when applicable), and (4) electricity costs.

The indirect costs consist of capital charges and overhead costs. Capital charges are defined as straight-line depreciation of net capital investment (excluding land and working capital), interim replacement of equipment (0.7 percent for pond or 2.5 percent for landfill of net capital investment), insurance and property taxes (at 2 percent of net capital and land), cost of capital (interest and dividends at 11.6 percent of depreciated total investment), and cost of income taxes (at 5.6 percent of depreciated total capital). The percentages associated with the last two components derive from the methodology (also used by TVA) that capital investment is funded by 60 percent debt (at 10 percent interest) and 40 percent equity (at 14 percent return to stockholders); i.e., 0.6 x 10 percent + 0.4 x 14 percent = 6 percent + 5.6 percent = 11.6 percent. So, if corporate income tax equals the return to stockholders, then income tax also represents 5.6 percent of depreciated total capital. It should be noted that, although cost of capital includes interest on land purchase, the purchase price of land is not being amortized or depreciated. This is identical to the TVA methodology, in which no explicit estimate of residual land value is assumed due to site-specific variables which are beyond the scope of this conceptualized analysis.

The overhead portions of indirect costs follow the TVA methodology of allocating an additional 50 percent of conversion costs (less electricity) for plant overhead, and another 10 percent of direct operating labor and supervision for administrative overhead. As Table 20 shows, total annual revenue requirement is thus the sum of all these direct and indirect costs.

The plant operating profile, as developed by TVA and adopted for this life-cycle analysis, requires a declining number of hours of plant operation over the disposal system's 30-year life span. The assumed annual hours of operation are as follows: 7,000 hours for each of the first 10 years, 5,000 hours for each of the next 5 years, 3,500 hours for each of the following 5 years, and 1,500 hours for each of the remaining 10 years of

20

TABLE 20. EXAMPLE ANNUAL REVENUE REQUIREMENTS*

Direct Costs		2,650
Delivered raw materials		859
Conversion cost		1,791
Operating labor and supervision	1,332	
Maintenance	172	
Analysis and operation	181	
Electricity	107	
Indirect Costs		3,576
Capital charges		2,601
Depreciation, interim replacement, insurance, and property taxes	758	
Cost of capital and income taxes	1,843	
Overhead		975
Plant	842	
Administration	133	
Total annual revenue requirements		6,227

* Source is TVA (4) base case for IUCS process, except (1) property taxes are for first-year capital value and (2) cost of capital and income taxes are for the first year of operation, rather than as a "levelized" average.

plant life. This means that the model plant operating profile consists of a total of 127,500 hours of operation for a total production of 6.375×10^{10} kilowatt hours produced over a 30-year period.

As the hours of operation decrease with plant age, the non-capital annual costs decrease also. Per the TVA methodology, it is assumed that raw materials, analysis and operation, electricity, and plant overhead decrease in direct proportion to annual hours of operation; direct charges for labor and supervision, as well as indirect charges for administrative overhead, are scaled proportional to annual operating hours raised to the 0.5 power; direct charges for maintenance are scaled proportional to annual operating hours raised to the 0.6 power. In this way, labor and maintenance costs recognize economies of scale and minimal labor requirements by decreasing less rapidly than hours of plant operation.

Example of Model Plant Cost Generation

Assumptions presented in the preceding sections allow model plant costs to be generated from TVA conceptual design estimates. As in the TVA report, capital costs include all construction and site improvements, vehicles and equipment, engineering design and supervision, contractor fees and start-up allowance, and all land and working capital. It only remains to make adjustment for fuel characteristics and other regional cost differentials.

Table 21 exemplifies this process of adjusting TVA cost estimates to reflect model plant assumptions. In this instance, the TVA unlined ponding base case has had its pond and land requirements adjusted to reflect lower model plant sludge generation. In combination with a lower construction index and lower land costs, this results in a decreased initial capital requirement and lower first-year indirect (i.e., capital charges) costs. Similarly, fuel characteristics and a lower O&M cost index produce lower first-year direct costs and lower indirect (i.e., overhead) costs. The result in Table 21 is total first-year costs for a western urban model plant which disposes of its sludge by unlined ponding.

The first-year costs do not reflect the assumed declining plant operating profile nor the present value of future revenue commitments for this model plant. Table 22 summarizes lifetime revenue commitments for the example model plant. As described previously, annual hours of plant operation are assumed to decrease in stepwise increments from 7,000 in Year 1 to 1,500 in Year 30. In this example, there are no delivered raw materials; but, if there were, they would also decrease in direct relation to hours of operation. The mechanisms by which the other costs decrease have already been discussed. It is interesting to note that since no inflation has been included, all categories except that for capital charges are already in terms of mid-1980 present value. Putting the capital charges in terms of present value

TABLE 21. ADAPTATION OF TVA CONCEPTUAL DESIGN COSTS: AN EXAMPLE FOR WESTERN URBAN UNLINED PONDING

	TVA Conceptual Design	SCS Model Plant
Fuel characteristics: %S	3½	2
%Ash	16	12
Construction cost index*	1,000	980
Plant capital investment#	$12,587	$10,498
Land cost/acre	$ 3,500	$ 707
Number of acres†	486	371
Land cost†#	$ 1,700	$ 262
Working capital#	$ 104	$ 104
Total initial capital investment#	$14,391	$10,864
O&M cost index*	1,000	908
Raw materials cost#	0	0
Labor and supervision cost#	$ 219	$ 198.80
Maintenance†#	$ 35.90	$ 214.20
Analysis and operation†#	$ 8.50	$ 7.72
Electricity†#	$ 55.30	$ 38.20
Total direct costs for the first year of operation†#	$ 518.70	$ 459
Total indirect costs for the first year of operation†# (see Table 20 for elaboration)	$ 2,246.40	$ 2,737
Total first year costs†#	$ 2,765.10	$ 3,196

* Relative to the TVA conceptual design (=1,000).

† Includes pond size adjustment to fuel characteristics.

# All costs in K$ for new 500-MW (30-yr life) disposal plant.

TABLE 22. EXAMPLE OF MODEL PLANT LIFETIME REVENUE COMMITMENTS (IN K$)

Year of Lower Unit Operation	Annual Hours of Operation	Cost of Delivered Raw Materials	Conversion Costs	Capital Charges	Overhead Charges	Annual Revenue Requirements	Annual Present Value* Revenue Requirements
1	7,000	0	459	2,507	230	3,196	3,196
2	7,000	0	459	2,447	230	3,136	2,882
3	7,000	0	459	2,387	230	3,076	2,606
4	7,000	0	459	2,327	230	3,016	2,363
5	7,000	0	459	2,266	230	2,956	2,150
6	7,000	0	459	2,206	230	2,895	1,964
7	7,000	0	459	2,146	230	2,835	1,800
8	7,000	0	459	2,086	230	2,775	1,657
9	7,000	0	459	2,026	230	2,715	1,531
10	7,000	0	459	1,966	230	2,655	1,421
11	5,000	0	376	1,905	191	2,472	1,203
12	5,000	0	376	1,845	191	2,412	1,119
13	5,000	0	376	1,785	191	2,352	1,045
14	5,000	0	376	1,725	191	2,292	981
15	5,000	0	376	1,665	191	2,232	925
16	3,500	0	305	1,604	157	2,066	771
17	3,500	0	305	1,544	157	2,006	729
18	3,500	0	305	1,484	157	1,946	691
19	3,500	0	305	1,424	157	1,886	659
20	3,500	0	305	1,364	157	1,826	631
21	1,500	0	187	1,304	99	1,589	431
22	1,500	0	187	1,243	99	1,529	409
23	1,500	0	187	1,183	99	1,469	391
24	1,500	0	187	1,123	99	1,408	375
25	1,500	0	187	1,063	99	1,348	362
26	1,500	0	187	1,003	99	1,288	350
27	1,500	0	187	942	99	1,228	340
28	1,500	0	187	882	99	1,168	331
29	1,500	0	187	822	99	1,107	323
30	1,500	0	187	762	99	1,047	317
			Cumulative costs			63,926	33,954
			Average cost in mills per KWh			1.00	.53

*After deflating capital charges by the (internal) rate of return, i.e., 11.6%.

requires deflating or discounting by some factor. In this case, it is the return to debt and equity financing (6 percent + 5.6 percent = 11.6 percent), otherwise known as the internal rate of return, which has been selected as the most appropriate discount factor. The final column of Table 22 reflects what happens when all future revenue requirements are put in terms of mid-1980 dollars. The cumulative lifetime cost to this model plant for this disposal method is nearly $34 million, which equates to an average present value revenue requirement of 0.53 mills per kilowatt hour (in terms of 1980 dollars). These costs are the incremental costs of sludge disposal, and are in addition to other model plant costs to produce electricity.

DISCUSSION OF UNIT COST RESULTS

Methods presented in the preceding sections were applied to each of the ten model plants, using each of the six disposal alternatives. The resulting 60 cost scenarios had capital investment requirements, per Tables 23 and 24; first-year operating revenue requirements, per Tables 25 and 26; and lifetime revenue requirements, per Tables 27 and 28.

However, it is the present value lifetime revenue commitment, shown at the bottom of the last column in Table 22, that is of particular interest. It is this parameter for the various model plants which most accurately measures future revenue commitments and forms the most appropriate basis of unit cost estimates. Tables 29 and 30 show these values for cumulative costs in thousands of dollars, and average unit revenue requirements in terms of mills per kilowatt hour.

The values presented in Table 30 (when stated to 10 significant digits) will be used, in following sections, to determine the economic impacts of various FGD regulatory scenarios. For this reason, it is important to note the great diversity of average unit costs shown in this table. Not only do unit costs per kilowatt hour vary considerably for each sludge disposal type under the various regional model plant scenarios, but the relative cost rankings between disposal types are not consistent from one region of the county to the next. This is as it should be when such factors as fuel composition, construction and O&M costs, and land prices are allowed to vary on a region-to-region and urban-to-rural basis. It is precisely this cost sensitivity to regional and local sludge disposal variations which will manifest itself in the resultant cost impact analysis.

INDUSTRY APPLICATION OF UNIT COSTS

In applying these model plant unit costs to the utility industry for each of the regulatory scenarios, it is necessary to assume that unit revenue requirements (per kilowatt hour) for the various disposal methods are invariant with respect to the size of the total plant disposal operation. This simplifying assumption appears to be at least partially substantiated by the TVA

TABLE 23. ESTIMATED CAPITAL INVESTMENT (K$) FOR ALL MODEL UTILITIES

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	10,864	10,672	13,369	12,440	15,425	14,259	12,125	11,253	14,357	13,216
Clay-lined Pond	13,602	13,410	14,371	13,442	21,901	20,734	13,699	12,827	17,431	16,190
Dry and Landfill	6,562	6,497	7,522	7,162	8,447	7,998	7,856	7,520	7,959	7,518
Dravo	17,179	17,033	20,448	20,236	27,459	26,665	19,211	18,549	24,010	23,037
IUCS†	8,228	8,128	9,246	8,915	12,126	11,604	9,346	8,893	10,685	10,232
Dry, Mix, and Landfill†	6,287	6,231	7,835	7,563	9,942	9,506	6,604	6,348	8,621	8,262

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

78

TABLE 24. ESTIMATED CAPITAL INVESTMENT ($/kW CAPACITY) FOR ALL MODEL UTILITIES

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	21.73	21.34	26.74	24.88	30.85	28.52	24.25	22.51	28.71	26.43
Clay-lined Pond	27.20	26.82	28.74	26.88	43.80	41.47	27.40	25.65	34.86	32.38
Dry and Landfill	13.12	12.99	15.04	14.32	16.89	16.00	15.71	15.04	15.92	15.04
Dravo	34.36	34.07	40.90	40.47	54.92	53.33	38.42	37.10	48.02	46.07
IUCS†	16.46	16.26	18.49	17.83	24.25	23.21	18.69	17.79	21.37	20.46
Dry, Mix, and Landfill†	12.57	12.46	15.67	15.13	19.88	19.01	13.21	12.70	17.24	16.52

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

TABLE 25. ESTIMATED FIRST-YEAR OPERATING REVENUE REQUIREMENTS (K$) FOR ALL MODEL UTILITIES

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	3,196	3,159	3,582	3,404	4,330	4,107	3,367	3,199	3,979	3,760
Clay-lined Pond	3,893	3,856	4,178	3,999	6,029	5,805	3,725	3,565	4,774	4,536
Dry and Landfill	3,374	3,362	4,316	4,247	4,732	4,646	3,942	3,878	4,322	4,237
Dravo	8,747	8,719	7,699	7,659	10,476	10,324	6,733	6,606	8,571	8,384
IUCS†	4,338	4,318	5,795	5,731	7,442	7,342	5,051	4,964	6,072	5,985
Dry, Mix, and Landfill†	2,789	2,778	4,370	4,317	5,323	5,239	3,432	3,383	4,334	4,265

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

TABLE 26. ESTIMATED FIRST-YEAR OPERATING REVENUE REQUIREMENTS (mills/kWh) FOR ALL MODEL UTILITIES

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	.91	.90	1.02	.97	1.24	1.17	.96	.91	1.14	1.07
Clay-lined Pond	1.11	1.10	1.19	1.14	1.72	1.66	1.06	1.02	1.36	1.30
Dry and Landfill	.96	.96	1.23	1.21	1.35	1.33	1.13	1.11	1.23	1.21
Dravo	2.50	2.49	2.20	2.19	3.00	2.95	1.92	1.89	2.45	2.39
IUCS†	1.24	1.23	1.65	1.64	2.13	2.10	1.44	1.42	1.73	1.71
Dry, Mix, and Landfill†	.80	.79	1.25	1.23	1.52	1.50	.98	.97	1.24	1.22

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

TABLE 27. ESTIMATED TOTAL LIFETIME REVENUE REQUIREMENTS (K$) FOR ALL MODEL PLANTS

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	63,926	62,820	72,861	67,510	88,817	82,101	69,190	64,167	82,119	75,546
Clay-lined Pond	77,509	76,403	85,380	80,029	121,967	115,245	76,061	71,209	97,631	90,483
Dry and Landfill	71,577	71,203	92,557	90,484	101,724	99,137	84,167	82,231	92,970	90,429
Dravo	168,405	167,564	151,988	150,767	206,664	202,090	133,983	130,170	170,557	164,953
IUCS†	89,799	89,223	121,371	119,465	154,889	151,882	106,556	103,947	126,985	124,375
Dry, Mix, and Landfill†	58,495	58,170	93,352	91,784	113,407	110,893	73,341	71,865	92,456	90,386

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

TABLE 28. ESTIMATED TOTAL LIFETIME REVENUE REQUIREMENTS (mills/kWh) FOR ALL MODEL PLANTS

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	1.00	.98	1.41	1.06	1.39	1.29	1.09	1.01	1.29	1.18
Clay-lined Pond	1.22	1.20	1.34	1.25	1.91	1.81	1.19	1.12	1.53	1.42
Dry and Landfill	1.12	1.12	1.45	1.08	1.60	1.55	1.32	1.29	1.46	1.42
Dravo	2.64	2.63	2.38	2.36	3.24	3.17	2.11	2.04	2.68	2.59
IUCS†	1.41	1.40	1.90	1.87	2.43	2.38	1.67	1.63	1.99	1.95
Dry, Mix, and Landfill†	.92	.91	1.46	1.44	1.78	1.74	1.15	1.13	1.45	1.42

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

69

TABLE 29. ESTIMATED PRESENT VALUE LIFETIME REVENUE REQUIREMENTS (K$) FOR ALL MODEL PLANTS

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	33,954	33,612	34,796	33,144	44,718	42,645	34,442	32,891	40,764	38,735
Clay-lined Pond	40,082	39,741	44,574	42,922	60,242	58,167	37,034	35,654	47,904	45,696
Dry and Landfill	51,064	50,948	68,708	68,068	74,853	74,055	59,243	58,645	67,583	66,799
Dravo	121,089	120,829	95,330	94,953	129,899	128,487	80,108	78,930	102,892	101,162
IUCS†	64,000	63,822	92,146	91,557	116,431	115,503	76,818	76,013	93,057	92,251
Dry, Mix, and Landfill†	38,852	38,751	68,630	68,146	81,940	81,163	52,438	51,982	65,143	64,504

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

TABLE 30. ESTIMATED PRESENT VALUE LIFETIME REVENUE REQUIREMENTS (mills/kWh) FOR ALL MODEL PLANTS

Model Plant Location*	Western		Midwestern				Eastern			
Fuel Type (Sulfur, Ash)	2, 12		3½, 12		5, 16		2, 12		3½, 16	
Construction Cost Index	980		1,000		1,000		988		988	
O&M Cost Index	908		1,049		1,049		935		935	
Land Cost ($/Acre)	707	188	2,878	799	2,878	799	3,608	1,259	3,608	1,259
Disposal Process										
Unlined Pond	.53	.53	.55	.52	.70	.67	.54	.52	.64	.61
Clay-lined Pond	.63	.62	.70	.67	.94	.91	.58	.56	.75	.72
Dry and Landfill	.80	.80	1.08	1.07	1.17	1.16	.93	.92	1.06	1.05
Dravo	1.90	1.90	1.49	1.49	2.04	2.02	1.26	1.24	1.61	1.59
IUCS†	1.00	1.00	1.44	1.44	1.83	1.81	1.20	1.19	1.46	1.45
Dry, Mix, and Landfill†	.61	.61	1.08	1.07	1.29	1.27	.82	.82	1.02	1.01

*Basic plant characteristics:
- 500 MW
- Limestone scrubbing @ 1.5 stoichiometry
- Fly ash collected with SO_2, unless otherwise noted.

†Fly ash collected separately and added to dewatered sludge.

conceptual design FGD disposal study, in which unit revenue requirements did not substantially change for generating capacities in excess of 500 MW.

With this in mind, it is necessary to make one further simplifying assumption in order to apply the model plant unit costs to the industry profiles: when determining remaining hours of future plant operation, it is assumed that industry plants conform to the TVA decreasing operating profile. In other words, a plant which will have been in operation for 4 years by mid-1980 is assumed to have done so at 7,000 hours per year, and to have a remaining productive life of 99,500 hours (127,500 hours useful life - 4 x 7,000 hours = 99,500 hours of useful life) over the remaining 26 years.

SECTION 8

UTILITY INDUSTRY RESPONSE TO REGULATORY SCENARIOS

METHODOLOGY AND ASSUMPTIONS FOR THE COST IMPACT ANALYSIS

As was described in Section 6, the five regulatory scenarios and their associated FGD sludge disposal requirements are as follows:

- Scenario No. 1 - No change from current trend in disposal practices.
- Scenario No. 2 - No urban ponding.
- Scenario No. 3 - No urban or rural ponding.
- Scenario No. 4 - No ponding; chemical fixation required for urban plants.
- Scenario No. 5 - No ponding; chemical fixation required for both urban and rural plants.

Applying each regulatory scenario to a model plant, it is assumed that the utility in question will select the lowest cost alternative that meets the regulatory criteria. To assess the industry-wide impact of these same regulatory scenarios, the projected 1980 and 1985 FGD capacity was described on a plant-by-plant basis in terms of the 10 model plants.

The resulting model industry profiles for 1980 and 1985 are presented in Tables 31 and 32, respectively.

In these two tables, the projected FGD capacity has been categorized by model plant characteristics and sludge disposal method. For those cases in which the sludge disposal method has yet to be selected, it was assumed that a new plant would base its decision on the relative costs (see Tables 29 and 30) of all available disposal alternatives. On the other hand, an existing plant would consider the "Dry, Mix, and Landfill" alternative only if fly ash were already collected separately in an electrostatic precipitator.

ESTIMATED INDUSTRY RESPONSE TO MORE STRINGENT REGULATIONS

The industry profile of FGD capacity, shown in Tables 31 and 32, was subjected to regulatory scenarios No. 2 through 5. The

TABLE 31. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 1, 1980

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	375	2,535	240	1,325		884		1,705		
Clay-Lined Pond				1,390						
Dry and Landfill		1,100		1,025	167					
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		815	250	2,779	1,790	184		360		
TOTALS	375	4,450	490	7,049	1,957	1,868	920	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 32. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 1, 1985

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	375	10,655	240	8,366		1,484	660	1,705		
Clay-Lined Pond				3,110						
Dry and Landfill		1,100		1,025	167					
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		815	250	2,779	2,450	184		360		
TOTALS	375	12,570	490	15,810	2,617	2,468	1,580	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

impact of each successive degree of regulation is to further limit the number of available disposal alternatives. Applying each scenario of the model industry profile, those plants which would be out of compliance were assumed to change to their least-cost alternative which still met the new requirements.

Tables 33 through 36 display the anticipated 1980 industry profiles resulting from implementation of scenarios No. 2 through 5, and Tables 37 through 40 show the 1985 profiles for scenarios No. 2 through 5.

As an example of how the industry response was estimated, consider the industry category of western urban unlined ponding. Since the 375 MW of existing capacity is assumed to collect SO_2 and fly ash wet, it cannot consider the "Dry, Mix, and Landfill" alternative. Hence, in going from scenario No. 1 for 1980 (Table 31) to the no-urban-ponding scenario No. 2 (Table 33), the response of this industry sector would be from unlined ponding to the cheapest remaining method of compliance and landfill. In terms of Table 30, this involves an increase in average present-value revenue requirements from 0.53 mills to 0.80 mills per kilowatt hour. Therefore, the impact of regulatory scenario No. 2 (shown in Table 33) is to convert this 375 MW of capacity to FGD sludge dewatering and landfill disposal.

The following discussion presents the results of similar cost impact analyses for all 10 model plants and 5 regulatory scenarios.

COST IMPACT OF THE UTILITY INDUSTRY RESPONSE

The methodology and assumptions presented in preceding sections were used to estimate future revenue commitments and capital investments in each of the key years for each coal-fired industry sector under each of the regulatory scenarios. The results of this analysis are presented in tabular form on the following pages. Total future revenue commitments under the various regulatory scenarios are shown in Tables 41 through 45 for mid-1980, and in Tables 46 through 50 for mid-1985. Total capital investments for each model industry sector under each regulatory scenario are shown in Tables 51 through 55 for mid-1980, and in Tables 56 through 60 for mid-1985.

Of additional interest are Tables 61 through 64, which identify the existing FGD sludge disposal capital investments which would be displaced by regulatory scenarios No. 2 through 5. Because these estimates include all land, equipment, and construction expenditures, they offer only an upper limit for estimating scenario-induced sunk costs to the utility industry. It is to be expected that the actual extent of these sunk costs will greatly depend on site-specific considerations and the nature of the disposal operation subsequently adopted.

TABLE 33. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 2, 1980

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		2,535		1,325		884		1,705		
Clay-Lined Pond				1,390						
Dry and Landfill	375	1,100	240	1,025	167					
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		815	250	2,779	1,790	184		360		
TOTALS	375	4,450	490	7,049	1,957	1,868	920	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 34. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 3, 1980

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	375	2,585	240	3,740	167	884		1,405		
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		1,865	250	2,779	1,790	184		660		
TOTALS	375	4,450	490	7,049	1,957	1,868	920	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 35. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 4, 1980

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		2,585		3,740		884		1,405		
Dravo									2,475	1,250
IUCS*	375		490	530	1,957	800	920		490	
Dry, Mix, and Landfill*		1,865		2,779		184		660		
TOTALS	375	4,450	490	7,049	1,957	1,868	920	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 36. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 5, 1980

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									2,475	1,250
IUCS*	375	4,450	490	7,049	1,957	1,868	920	2,065	490	
Dry, Mix, and Landfill*										
TOTALS	375	4,450	490	7,049	1,957	1,868	920	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 37. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 2, 1985

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		10,655		8,366		1,484		1,705		
Clay-Lined Pond				3,110						
Dry and Landfill	375	1,100	240	1,025	167					
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		815	250	2,779	2,450	184	660	360		
TOTALS	375	12,570	490	15,810	2,617	2,468	1,580	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

99

TABLE 38. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 3, 1985

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	375	2,585	240	12,501	167	884		1,405		
Dravo									2,475	1,250
IUCS*				530		800	920		490	
Dry, Mix, and Landfill*		9,985	250	2,779	2,450	784	660	660		
TOTALS	375	12,570	490	15,810	2,617	2,468	1,580	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 39. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 4, 1985

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		2,585		12,501		884		1,405		
Dravo									2,475	1,250
IUCS*	375		490	530	2,617	800	1,580		490	
Dry, Mix, and Landfill*		9,985		2,779		784		660		
TOTALS	375	12,570	490	15,810	2,617	2,468	1,580	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

TABLE 40. DISTRIBUTION OF UTILITY FGD SLUDGE DISPOSAL CAPACITY, SCENARIO NO. 5, 1985

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									2,475	1,250
IUCS*	375	12,570	490	15,810	2,617	2,468	1,580	2,065	490	
Dry, Mix, and Landfill*										
TOTALS	375	12,570	490	15,810	2,617	2,468	1,580	2,065	2,965	1,250

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in MW's of generating capacity.

102

TABLE 47: REGULATORY SCENARIO NO. 1, YEAR 1980, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	18,009	151,424	9,366	65,164		47,020		96,936		
Clay-Lined Pond				96,324						
Dry and Landfill		112,086		125,152	14,020					
Dravo									444,070	245,963
IUCS*				81,066		159,439	95,628		88,641	
Dry, Mix, and Landfill*		56,228	32,431	329,736	251,921	26,588		33,317		
TOTALS	18,009	319,738	41,797	697,442	265,941	233,047	95,628	130,253	532,711	245,963

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 42. REGULATORY SCENARIO NO. 2, YEAR 1980, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		151,424		65,164		47,020		96,936		
Clay-Lined Pond				96,324						
Dry and Landfill	27,084	112,086	18,495	125,152	14,020					
Dravo									444,070	245,963
IUCS*				81,066		159,439	95,628		88,641	
Dry, Mix, and Landfill*		56,228	32,431	329,736	251,921	26,588		33,317		
TOTALS	27,084	319,738	50,926	697,442	265,941	233,047	95,628	130,253	532,711	245,963

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 43. REGULATORY SCENARIO NO. 3, YEAR 1980, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	27,084	234,619	18,495	411,734	14,020	81,652		137,650		
Dravo									444,070	245,963
IUCS*				81,066		159,439	95,628		88,641	
Dry, Mix, and Landfill*		137,606	32,431	329,736	251,921	26,588		64,307		
TOTALS	27,084	372,225	50,926	822,536	265,941	267,679	95,628	201,957	532,711	245,963

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 44. REGULATORY SCENARIO NO. 4, YEAR 1980, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		234,619		411,734		81,652		137,650		
Dravo									444,070	245,963
IUCS*	33,945		68,347	81,066	379,771	159,439	95,628		88,641	
Dry, Mix, and Landfill*		137,606		329,736		26,588		64,307		
TOTALS	33,945	372,225	68,347	822,536	379,771	267,679	95,628	201,957	532,711	245,963

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 45. REGULATORY SCENARIO NO. 5, YEAR 1980, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									444,070	245,963
IUCS*	33,945	520,537	68,347	1,077,896	379,771	324,630	95,628	272,744	88,641	
Dry, Mix, and Landfill*										
TOTALS	33,945	520,537	68,347	1,077,896	379,771	324,630	95,628	272,744	532,711	245,963

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 46. REGULATORY SCENARIO NO. 1, YEAR 1985, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	11,285	650,746	5,567	510,100		79,691	45,463	66,147		
Clay-Lined Pond				211,220						
Dry and Landfill		81,317		86,847	8,334					
Dravo									304,258	176,538
IUCS*				54,424		108,709	58,803		63,607	
Dry, Mix, and Landfill*		38,889	23,011	225,764	281,178	18,389		23,043		
TOTALS	11,285	770,952	28,578	1,088,355	289,512	206,789	104,266	89,190	367,865	176,538

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 47. REGULATORY SCENARIO NO. 2, YEAR 1985, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		650,746		510,100		79,691		66,147		
Clay-Lined Pond				211,220						
Dry and Landfill	16,971	81,317	10,993	86,847	8,334					
Dravo									304,258	176,538
IUCS*				54,424		108,709	58,803		63,607	
Dry, Mix, and Landfill*		38,889	23,011	225,764	281,178	18,389	69,218	23,043		
TOTALS	16,971	770,952	34,004	1,088,355	289,512	206,789	128,021	89,190	367,865	176,538

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 48. REGULATORY SCENARIO NO. 3, YEAR 1985, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	16,971	162,680	10,993	1,469,407	8,334	49,521		92,413		
Dravo									304,258	176,538
IUCS*				54,424		108,709	58,803		63,607	
Dry, Mix, and Landfill*		727,244	23,011	225,764	281,178	115,785	69,218	45,671		
TOTALS	16,971	889,924	34,004	1,749,595	289,512	274,015	128,021	138,084	367,865	176,538

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 49. REGULATORY SCENARIO NO. 4, YEAR 1985, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		162,680		1,469,407		49,521		92,413		
Dravo									304,258	176,538
IUCS*	21,271		45,639	54,424	412,497	108,709	160,203		63,607	
Dry, Mix, and Landfill*		727,244		225,764		115,785		45,671		
TOTALS	21,271	889,924	45,639	1,749,595	412,497	274,015	160,203	138,084	367,865	176,538

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 50. REGULATORY SCENARIO NO. 5, YEAR 1985, TOTAL FUTURE REVENUE COMMITMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									304,258	176,538
IUCS*	21,271	1,401,541	45,639	2,334,220	412,497	350,720	160,203	186,566	63,607	
Dry, Mix, and Landfill*										
TOTALS	21,271	1,401,541	45,639	2,334,220	412,497	350,720	160,203	186,566	367,865	176,538

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 51. REGULATORY SCENARIO NO. 1, YEAR 1980, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148	54,107	6,417	32,077		25,210		38,373		
Clay-Lined Pond				37,369						
Dry and Landfill		14,293		14,682	2,821					
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		10,157	3,918	42,035	35,592	3,498		4,571		
TOTALS	8,148	78,557	10,335	135,613	38,413	47,274	17,197	42,944	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 52. REGULATORY SCENARIO NO. 2, YEAR 1980, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		54,107		32,077		25,210		38,373		
Clay-Lined Pond				37,369						
Dry and Landfill	4,922	14,293	3,611	14,682	2,821					
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		10,157	3,918	42,035	35,592	3,498		4,571		
TOTALS	4,922	78,557	7,529	135,613	38,413	47,274	17,197	42,944	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 53. REGULATORY SCENARIO NO. 3, YEAR 1980, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	4,922	33,589	3,611	53,060	2,821	14,140		21,131		
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		23,242	3,918	42,035	35,592	3,498		8,379		
TOTALS	4,922	56,831	7,529	104,545	38,413	36,204	17,197	29,510	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 54. REGULATORY SCENARIO NO. 4, YEAR 1980, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		33,589		53,060		14,140		21,131		
Dravo									118,850	57,593
IUCS*	6,171		9,061	9,450	47,461	18,566	17,197		10,471	
Dry, Mix, and Landfill*		23,242		42,035		3,498		8,379		
TOTALS	6,171	56,831	9,061	104,545	47,461	36,204	17,197	29,510	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 55. REGULATORY SCENARIO NO. 5, YEAR 1980, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									118,850	57,593
IUCS*	6,171	72,339	9,061	125,047	47,461	43,353	17,197	36,728	10,471	
Dry, Mix, and Landfill*										
TOTALS	6,171	72,339	9,061	125,047	47,461	43,353	17,197	36,728	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 56. REGULATORY SCENARIO NO. 1, YEAR 1985, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148	227,420	6,417	207,257		42,321	16,005	38,373		
·Clay-Lined Pond				83,609						
Dry and Landfill		14,293		14,682	2,821					
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		10,157	3,918	42,035	48,715	3,498		4,571		
TOTALS	8,148	251,870	10,335	357,033	51,536	64,385	33,202	42,944	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 57. REGULATORY SCENARIO NO. 2, YEAR 1985, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond		227,420		207,257		42,321		38,373		
Clay-Lined Pond				83,609						
Dry and Landfill	4,922	14,293	3,611	14,682	2,821					
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		10,157	3,918	42,035	48,715	3,498	8,717	4,571		
TOTALS	4,922	251,870	7,529	357,033	51,536	64,385	25,914	42,944	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 58. REGULATORY SCENARIO NO. 3, YEAR 1985, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill	4,922	33,589	3,611	178,553	2,821	14,140		21,131		
Dravo									118,850	57,593
IUCS*				9,450		18,566	17,197		10,471	
Dry, Mix, and Landfill*		124,433	3,918	42,035	48,715	14,905	8,717	8,379		
TOTALS	4,922	158,022	7,529	230,038	51,536	47,611	25,914	29,510	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 59. REGULATORY SCENARIO NO. 4, YEAR 1985, TOTAL CAPITAL INVESTMENTS Year 1

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill		33,589		178,553		14,140		21,131		
Dravo									118,850	57,593
IUCS*	6,171		9,061	9,450	63,467	18,566	29,534		10,471	
Dry, Mix, and Landfill*		124,433		42,035		14,905		8,379		
TOTALS	6,171	158,022	9,061	230,038	63,467	47,611	29,534	29,510	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 60. REGULATORY SCENARIO NO. 5, YEAR 1985, TOTAL CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond										
Clay-Lined Pond										
Dry and Landfill										
Dravo									118,850	57,593
IUCS*	6,171	204,338	9,061	281,256	63,467	57,278	29,534	36,728	10,471	
Dry, Mix, and Landfill*										
TOTALS	6,171	204,338	9,061	281,256	63,467	57,278	29,534	36,728	129,321	57,593

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

2

TABLE 61. REGULATORY SCENARIO NO. 2, YEAR 1980, TOTAL DISPLACED CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148		6,417							
Clay-Lined Pond										
Dry and Landfill										
Dravo										
IUCS*										
Dry, Mix, and Landfill*										
TOTALS	8,148		6,417							

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

3

TABLE 62. REGULATORY SCENARIO NO. 3, YEAR 1980, TOTAL DISPLACED CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148	54,107	6,417	32,077		25,210		38,373		
Clay-Lined Pond				37,369						
Dry and Landfill										
Dravo										
IUCS*										
Dry, Mix, and Landfill*										
TOTALS	8,148	54,107	6,417	69,446		25,210		38,373		

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 63. REGULATORY SCENARIO NO. 4, YEAR 1980, TOTAL DISPLACED CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148	54,107	6,417	32,077		25,210		38,373		
Clay-Lined Pond				37,369						
Dry and Landfill					2,821					
Dravo										
IUCS*										
Dry, Mix, and Landfill*			3,918		35,592					
TOTALS	8,148	54,107	10,335	69,446	38,413	25,210		38,373		

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

TABLE 64. REGULATORY SCENARIO NO. 5, YEAR 1980, TOTAL DISPLACED CAPITAL INVESTMENTS

Location	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2	
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Disposal Process										
Unlined Pond	8,148	54,107	6,417	32,077		25,210		38,373		
Clay-Lined Pond				37,369						
Dry and Landfill		14,293		14,682	2,821					
Dravo										
IUCS*										
Dry, Mix, and Landfill*		10,157	3,918	42,035	35,592	3,498		4,571		
TOTALS	8,148	78,557	10,335	126,163	38,413	28,708		42,944		

*Fly ash collected separately and added to dewatered sludge.

NOTE: All amounts in 1,000's of 1980 $.

Because of the amount of information generated, Section 9 will summarize the salient points of these analysis results. The interested reader is encouraged to examine the data presented in the tables, particularly those estimates which apply to the industry section with which he is most familiar. The following example demonstrates the derivation and significance of this tabular information.

Consider again the 1980 industry sector for western urban unlined ponding under the no-change scenario No. 1. By 1980, the 375-MW capacity of this sector (see Table 31) will be composed of a 6-year-old 250-MW plant (85,500 remaining hours), and a 4-year-old 125-MW plant (99,500 remaining operating hours). The total remaining electricity production potential for these two plants is 3.38×10^{10} kilowatt hours. At an average present value FGD sludge disposal cost of 0.533 mills per kilowatt hour (see Table 30), a future revenue commitment of $18,009,000 is required.

The procedure for determining this same sector's capital commitment is similar to the above methodology, in that the model plant capital costs for disposal per kilowatt of generating capacity ($21.73 for western urban unlined ponding, Table 24) are multiplied by the associated generating capacity. An estimated initial FGD sludge disposal capital investment of $8,148,000 was made by this sector under regulatory scenario No. 1.

Under regulatory scenario No. 2 for 1980, the FGD sludge disposal capacity of this sector is assumed to shift from unlined ponding to landfill disposal of dewatered sludge and fly ash. From the preceding discussion, the future revenue commitment increases to $27,084,000 as a result of the more stringent regulation.

The same methodology is employed for estimating 1985 cost impacts. Because plants included in the 1980 industry profile would be 5 years older by 1985, the associated remaining hours of productive operation must be adjusted accordingly. For the 250-MW and 125-MW western plants used in this example, their respective ages would be 11 and 9 years, and their remaining hours would be decreased by 33,000 and 35,000 hours, respectively, from the 1980 estimates. The result of these changes is that future revenue commitments of this sector after 1985 for regulatory scenario No. 1 (in terms of 1980 dollars) would become $11,285,000, a substantial decrease from the estimated 1980 commitment of $18,009,000. It should be noted, however, that several other model industry sectors are planning to add FGD capacity after mid-1980, and will instead experience an increase in revenue commitment after mid-1985.

SECTION 9

ANALYSIS OF ESTIMATED UTILITY INDUSTRY IMPACTS

It is possible to assess the economic impacts of regulatory scenarios No. 2 through 5 in terms of the no-change scenario No. 1, from the estimated total dollar amounts for coal-fired utility future revenues and capital investments required for FGD disposal (as developed in Tables 41 through 60 of Section 8). Tables 65 and 66 summarize these economic impacts to each industry sector for the years 1980 and 1985.

Returning to the example of the western urban sector in 1980, Table 65 shows an increase in future revenue requirements of $9 million when regulatory scenario No. 2 replaces No. 1. This is in addition to the $18 million already expected under regulatory scenario No. 1. Scenario No. 4 will require this sector to make an additional revenue commitment of $16 million. Although this sector would experience increased total future revenue commitments under scenarios No. 2 through 5, the lower portion of Table 65 shows that these scenarios would require less capital-intensive forms of disposal, possibly because the disposal systems required under scenarios No. 2 through 5 tend to need less land and greater raw material inputs.

The far right column of Table 65 shows an estimated 1980 future revenue commitment of $2.58 billion by the coal-fired electric utility industry under the no-change regulatory scenario No. 1. This amount increases by $972 million under the most restrictive regulatory scenario considered. Although industry-wide future revenue requirements for FGD sludge disposal increase under scenarios No. 2 through 5, the total initial capital requirements are expected to decrease slightly from $565 million under scenario No. 1 to $544 million under scenario No. 5. Thus, the more restrictive scenarios are expected to offer some small relief to the financing requirements of most coal-fired utility industry sectors.

Table 66 presents a similar but more dramatic picture than Table 65. A larger portion of generating capacity is expected to be coal-fired in 1985 than in 1980. For this reason, future revenue commitments under scenario No. 1 are shown to rise to $3.133 billion (new plants were assumed to be free under scenario No. 1 to consider all types of FGD sludge disposal). Under regulatory scenario No. 5, future revenue requirements for sludge disposal increase $2.324 billion to an impressive industry total of $5.467 billion. As noted for Table 65, total industry capital

TABLE 65. SUMMARY OF REGULATORY SCENARIO IMPACTS FOR 1980

Location/Coal Type		Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2		Industry Sum/ Difference
Setting		Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	
Regulatory Scenario No.												
1	Total Future Revenue Commitments	18	320	42	700	266	233	96	130	533	246	2,580
2	Increase in Total Future Revenue Commitments	9	0	9	0	0	0	0	0	0	0	18
3		9	52	9	125	0	35	0	72	0	0	302
4		16	52	26	125	114	35	0	72	0	0	440
5		16	201	26	380	114	91	0	142	0	0	972
1	Total Capital Investments	8	78	10	136	38	47	17	43	129	57	565
2	Increase in Total Capital Investments*	-3	0	-3	0	0	0	0	0	0	0	-6
3		-3	-22	-3	-31	0	-11	0	-13	0	0	-83
4		-2	-22	-1	-31	9	-11	0	-13	0	0	-71
5		-2	-6	-1	-10	9	-4	0	-6	0	0	-21

*Does not include any sunk costs for displaced disposers.
NOTE: All amounts are in 10^6 of 1980 $.

TABLE 66. SUMMARY OF REGULATORY SCENARIO IMPACTS FOR 1985

Location/Coal Type		Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2		Industry Sum/ Difference
Setting		Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	
Regulatory Scenario No.												
1	Total Future Revenue Commitments	11	771	28	1,088	289	207	104	89	368	176	3,133
2	Increase in Total Future Revenue Commitments	6	0	5	0	0	0	24	0	0	0	35
3		6	119	5	661	0	67	24	49	0	0	931
4		10	119	17	661	123	67	56	49	0	0	1,102
5		10	631	17	1,246	123	144	56	97	0	0	2,324
1	Total Capital Investments	8	252	10	357	51	64	33	43	129	57	1,006
2	Increase in Total Capital Investments*	-3	0	-3	0	0	0	-7	0	0	0	-13
3		-3	-94	-3	-127	0	-17	-7	-13	0	0	-264
4		-2	-94	-1	-127	12	-17	-4	-13	0	0	-264
5		-2	-48	-1	-76	12	-7	-4	-6	0	0	-132

*Does not include any sunk costs for displaced disposers.
NOTE: All amounts are in 10^6 of 1980 $.

112

requirements by 1985 are reduced somewhat by the more restrictive regulatory scenarios, but the increases in present value lifetime costs to the consumer far outweigh these capital savings.

Table 67 summarizes Tables 41 through 50 in terms of ultimate electricity cost to the consumer (in mid-1980 mills per kilowatt hour). The last two columns in Table 67 summarize economic impacts to the consumer in average mills per future kilowatt hour, and by the percent increase over regulatory scenario No. 1. The industry averages are not simple averages, but are weighted in terms of future hours of electrical production. Thus, the percent increases actually reflect additional plant capacities and remaining life spans (which determine remaining kilowatt hours of production), as well as future revenue requirements. The relatively larger increments in percent increases for regulatory scenarios No. 3 and No. 5 are primarily due to the greater total generating capacities that will be located in rural rather than urban settings (see Tables 31 and 32).

The economic impacts of scenarios No. 2 through 5 appear to be proportionately greater for the western region. But in terms of absolute differences, the midwestern region appears to bear the greatest incremental costs under these scenarios (see Tables 65 and 66).

It also appears from Table 67 that each regulatory scenario has a relatively greater impact (i.e., percent increase) in 1985 than in 1980. This difference is partially due to the fact that, because of more rural plants, the industry average cost is much lower for scenario No. 1 in 1985 than it is in 1980. This difference is also partially due to the greater freedom of disposal choice open to new plants coming on line after mid-1980.

The averages do not include, however, the sunk costs of those capital investments already made under scenario No. 1, which are no longer usable under regulatory scenarios No. 2 through 5. Because these additional incremental costs were not included in this analysis, some caution is appropriate when comparing average cost impacts for 1980 to those for 1985.

SCENARIO 1

TABLE 67. SUMMARY OF REGULATORY SCENARIO IMPACTS TO CONSUMERS (mills/kWh)*

Location/ Coal Type	Western		Midwestern No. 1		Midwestern No. 2		Eastern No. 1		Eastern No. 2		Industry Average	Percent Increase Over Scenario No. 1
Setting	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural		
Regulatory Scenario No.	For the Year 1980:											
1	.53	.61	.88	.93	1.28	1.30	1.20	.57	1.59	1.59	1.017	—
2	.80	.61	1.08	.93	1.28	1.30	1.20	.57	1.59	1.59	1.024	0.7
3	.80	.72	1.08	1.10	1.28	1.49	1.20	.88	1.59	1.59	1.136	11.7
4	1.00	.72	1.44	1.10	1.83	1.49	1.20	.88	1.59	1.59	1.190	17.1
5	1.00	1.00	1.44	1.44	1.83	1.81	1.20	1.19	1.59	1.59	1.400	37.7
Regulatory Scenario No.	For the Year 1985:											
1	.53	.55	.91	.67	1.28	1.07	.78	.57	1.59	1.59	.759	—
2	.80	.55	1.08	.67	1.28	1.07	.96	.57	1.59	1.59	.767	1.1
3	.80	.64	1.08	1.08	1.28	1.42	.96	.88	1.59	1.59	.984	29.7
4	1.00	.64	1.44	1.08	1.83	1.42	1.20	.88	1.59	1.59	1.026	35.2
5	1.00	1.00	1.44	1.44	1.83	1.81	1.20	1.19	1.59	1.59	1.321	74.2

*All amounts are in present value as of mid-1980.

~~131~~ 114

REFERENCES

1. Barrier, J. W., H. L. Faucett, and L. J. Henson. Conceptual Design and Economic Evaluation of Alternative Methods for Disposal of Lime-Limestone Scrubbing Wastes. Draft. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977. 221 pp.

2. Barrier, J. W., H. L. Faucett, and L. J. Henson. Economic Assessment of Flue Gas Desulfurization Sludge Disposal Alternatives. J. Environ. Eng. Div. Am. Soc. Civ. Eng., 104(EE5): 951-966, October 1978.

3. Barrier, J. W., H. L. Faucett, and L. J. Henson. Economics of Disposal of Lime-Limestone Scrubbing Wastes: Sludge-Flyash Blending and Gypsum Systems. Draft. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. 187 pp.

4. Barrier, J. W., H. L. Faucett, and L. J. Henson. Economics of Disposal of Lime-Limestone Scrubbing Wastes: Untreated and Chemically Treated Wastes. EPA-600/7-78-023a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. 416 pp.

5. Edwards, R. G., A. B. Broderson, and W. P. Hauser. Social, Economic, and Environmental Impacts of Coal Gasification and Liquefaction Plants. IMMR 14-GR2-76, Institute for Mining and Minerals Research, University of Kentucky, Lexington, Kentucky, 1976. 269 pp. (Available from National Technical Information Service (NTIS) as PB-253 747).

6. Employment and Earnings (U.S. Bureau of Labor Statistics) 24(11):1-138, November 1977.

7. Federal Energy Administration, Office of Utility Project Operations. Inventory of Power Plants in the United States. FEA/G-77/202, June 1977. 350 pp. (Available from National Technical Information Service (NTIS) as PB-269 867).

8. Fling, R. B., W. M. Graven, F. O. Hess, P. P. Leo, R. C. Rossi, and J. Rossoff. Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation; Initial Report. EPA-600/2-76-070, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1976. 219 pp. (Available from National Technical Information Service (NTIS) as PB-251 876).

9. Fling, R. B., W. M. Graven, P. P. Leo, and J. Rossoff. Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation; Second Annual Report. EPA-600/7-78-024, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. 184 pp.

10. Le, T., E. Rubin, and P. Meier. Coal Utilization in the Northeast. Volume VIII. Solid Waste Management Issues and Impacts. Draft. U.S. Department of Energy, Washington, D.C., 1978. 93 pp.

11. Lunt, R. R., C. B. Cooper, S. L. Johnson, J. E. Oberholtzer, G. R. Schimke, and W. I. Watson. An Evaluation of the Disposal of Flue Gas Desulfurization Wastes in Mines and the Ocean: Initial Assessment. EPA-600/7-77-051, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977. 318 pp. (Available from National Technical Information Service (NTIS) as PB-269 270).

12. McGlamery, G. G., R. L. Torstrick, W. J. Broadfoot, J. P. Simpson, L. J. Henson, S. V. Tomlinson, and J. F. Young. Detailed Cost Estimates for Advanced Effluent Desulfurization Process. EPA-600/2-75-006, U.S. Environmental Protection Agency, Washington, D.C., 1975. 417 pp. (Available from National Technical Information Service (NTIS) as PB-242 541).

13. Michael Baker Jr., Inc. State-of-the-Art of Sludge Fixation. Draft. Research Project 786-1, Task 3, Beaver, Pennsylvania, 1977. 251 pp.

14. Murphy, B. L., G. F. Hoffnagle, J. R. Mahoney, and J. L. Watson. Energy Consumption of Environmental Controls: Fossil Fuel, Steam Electric Generating Industry. In: Energy and the Environment. Proceedings of the Fifth National Conference, American Institute of Chemical Engineers, Cincinnati, Ohio, 1977. pp. 174-179.

15. Oglesby, S., Jr., and G. Nichols. Particulate Control Highlights: Research on Electrostatic Precipitator Technology. EPA-600/8-77-020a, U.S. Environmental Protection Agency, Washington, D.C., 1977. 16 pp. (Available from National Technical Information Service (NTIS) as PB-276 643).

16. Pedco Environmental, Inc. Summary Report - Flue Gas Desulfurization Systems. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1977. 415 pp.

17. SCS Engineers. Chemical Speciation of Flue Gas Desulfurization Constituents. Draft. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977.

18. Taylor, G. C., and O. W. Albrecht. A Framework for Economic Analysis of Hazardous Wastes Management Alternatives. In: Land Management of Hazardous Wastes, Proceedings of the Fourth Annual Research Symposium, San Antonio, Texas, March 6, 7, and 8, 1978. D. W. Shultz, ed. EPA-600/9-78-016, U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1978. pp. 55-73.

19. Temple, Barker & Sloane, Inc. An Analysis of Recent Electric Utility Rate Increases. U.S. Environmental Protection Agency, Washington, D.C., 1975. 99 pp. (Available from National Technical Information Service (NTIS) as PB-257 718).

20. Temple, Barker & Sloane, Inc. Economic and Financial Impacts of Federal Air and Water Pollution Controls on the Electric Utility Industry. EPA-230/3-76-013, U.S. Environmental Protection Agency, Washington, D.C., 1976. 403 pp. (Available from National Technical Information Service (NTIS) as PB-254 308).

21. Temple, Barker & Sloane, Inc. Economic and Financial Impacts of Federal Air and Water Pollution Controls on the Electric Utility Industry. Executive Summary. EPA-230/3-76-013, U.S. Environmental Protection Agency, Washington, D.C., 1976. 32 pp. (Available from National Technical Information Service (NTIS) as PB-254 307).

22. U.S. Bureau of the Census. 1974 Census of Agriculture. Washington, D.C.

23. U.S. Department of Agriculture. Economic Research Service. Balance sheet of the farming sector. Agricultural Information Bulletin 411, Washington, D.C., 1977. 53 pp.

24. U.S. Environmental Protection Agency, Effluent Guidelines Division. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category. EPA-400/1-74 029a, October 1974. 840 pp.

25. Weaver, D. E., C. J. Schmidt, and J. P. Woodyard. Data Base for Standards/Regulations Development for Land Disposal of Flue Gas Cleaning Sludges. EPA-600/7-77-118, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 285 pp.

26. Weeter, D. W. University of Tennessee. State-of-the-Art Review of FGD Sludge Stabilization Using Admixtures. Presented at the 71st Air Pollution Control Association Annual Meeting and Exhibition, Houston, Texas, June 25-30, 1978.

27. Whitman, Requard and Associates. Handy-Whitman indexes: electric utility construction. Eng. News-Rec., 199(12):97, September 22, 1977.

28. Federal Power Commission. Form 67 Data (unpublished). 1976.